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MISCELLANEOUS CONTRIBUTIONS TO OCEANOGRAPHY AND FISHERIES BIOLOGY

Cape Town

1968

Republic of South Africa
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TRENDS IN THE ABUNDANCE OF WEST COAST ROCK LOBSTER, *JASUS LALANDII* (MILNE-EDWARDS)*

A. E. F. Heydorn, G. G. Newman and G. S. Rossouw

INTRODUCTION

The exploitation of the West Coast rock lobster, *Jasus lalandii* (H. Milne-Edwards), is one of the oldest and most important aspects of the South African fishing industry. This species occurs in quantity along the rocky shoreline of the West Coast, in depths ranging from 1 to 80 fathoms (Fig. 1). Although the vessels employed for the capture of rock lobster have advanced in design from rowing to outboard-powered dinghies and from sail to diesel powered motor vessels, the basic fishing technique has remained practically unchanged since the early days of the industry. This involves the use of baited nets and traps connected to a surface marker buoy by means of a hauling line, a technique described by Heydorn† (1965). In the same paper it was stated that representations have been made to the Government by sections of the rock lobster industry, requesting concessions with regard to conservational measures. These were motivated by an apparent decline in availability of stocks. The present investigation was undertaken to determine whether such declines could be substantiated by an analysis of catch statistics.

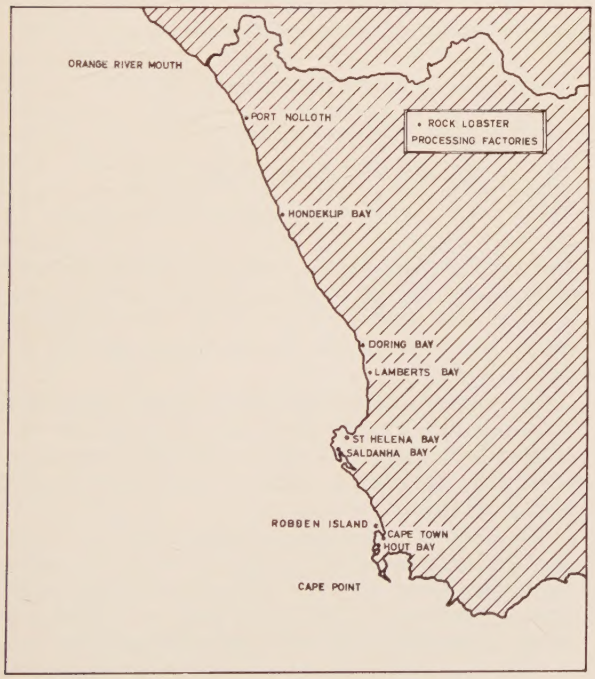


FIG. 1. Position of West Coast rock lobster factories

Current fisheries theory states that a biological population which is subjected to exploitation, can compensate for the increased mortality by means of accelerated recruitment rates and more rapid growth—Graham‡ (1943) and Rounsefell and Everhard** (1953).

This resilience allows intense exploitation of stocks without endangering their future productivity or yield. Ideally, the sustained yield can be maximised at a certain level. If the necessary data for the assessment of this level are not available, exploitation at too high a level is usually only recognised when catches decline in spite of ever increasing fishing effort. Should this state of affairs persist, a stage must be reached when it becomes uneconomical to fish due to reduced productivity of stocks. In this manner permanent damage can be inflicted on the resource, particularly in slow-growing species, or in areas in which conditions of pronounced inter-specific competition prevail.

The present investigation is not based on a planned programme, but rather on the piecing together of information obtained from various sources. These were:

(*a*) test catches by research vessels of the Division of Sea Fisheries during the period 1952–1956,

(*b*) catch figures provided by commercial concerns for the period 1953–1964 and

(*c*) the size composition of tails marketed during the period September 1957 to December 1964.

Consequently, the results are somewhat fragmentary and subject to such limitations as inadequate time and incomplete geographical coverage. The trends which emerge are clear enough, however, to give some indication of the effect of the substantial exploitation of the past decade on the West Coast rock lobster resources.

* S.A. Shipping News XX (10): 91–103, 1965.

† HEYDORN, A. E. F., 1965. *Investl Rep. Div. Sea Fish. S. Afr.* 53: 1–32.

‡ GRAHAM, M., 1943. *The Fish Gate*. Faber and Faber, Ltd., 196 pp., London.

** ROUNSEFELL, G. A., and W. A. EVERHART, 1953. *Fishery Science, its Methods and Applications*. John Wiley and Sons, Inc., 444 pp., New York.

ASSESSMENT OF CHANGES IN RELATIVE ABUNDANCE

During the period 1952–1956, the research vessels *Palinurus* and *Schipa* of the Division of Sea Fisheries conducted experimental rock lobster fishing in the area between Duiker Point and Logies Rock (Fig. 2). This work was conducted whenever these vessels were not committed to its substantial routine research programme.

The Duiker Point to Logies Rock area was part of a proclaimed sanctuary from November 1940 to July 1952, after which period it was opened to commercial fishing until August 1960. Since it is within easy reach of boats from both Hout Bay and Cape Town, intensive fishing took place here between 1952 and 1956. This area is, therefore, considered to be particularly suitable for observing the effect of heavy exploitation on a rock lobster population which had previously been undisturbed for a long period.

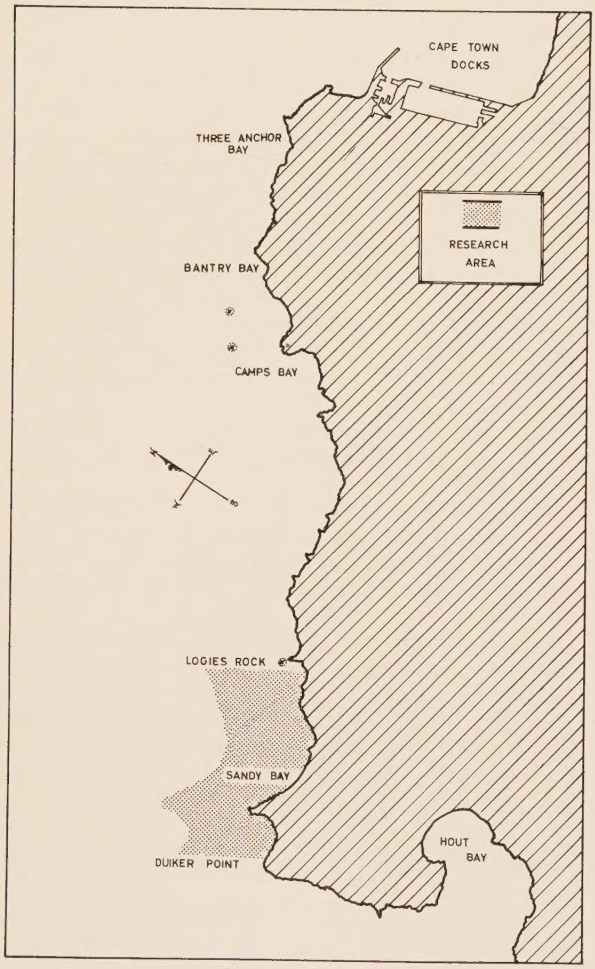


FIG. 2. Logies Rock to Duiker Point research area

The research vessels conducted their experimental fishing in the same way as the commercial boats, i.e. with hoop nets which are lowered and raised from dinghies. The maximum fishing depth was 25 fathoms. The unsorted catch was brought on board, where the size, sex and the state of the carapace of each animal was recorded together with notes concerning:

(*a*) date and position of catch,
(*b*) the number of hauls made,
(*c*) the fishing time.

Thus it was possible to calculate the catch per unit effort in terms of *numbers of rock lobsters per size class per haul.*

As the abdomen or tail was the only part of the rock lobster utilised by the industry for export purposes during the period of investigation, the catch per unit effort can be described more precisely in terms of *tail weight/haul*, as this measure of abundance refers not only to the numerical catch but also to its size composition.

The conversion from numbers within size classes to total tail weight was done by using carapace length/tail weight relationships calculated separately for males and females. These were:

$$\text{Males:} \quad W_t = 0{\cdot}2868\ L_c^{2{\cdot}7001}$$

$$\text{Females:} \quad W_t = 0{\cdot}1873\ L_c^{2{\cdot}9883}$$

Where W_t = tail weight in g
L_c = carapace length in cm.

The above relationships were calculated from the dimensions of 499 male and 452 female rock lobsters. The data from which the *tail weight/haul* (*catch per unit effort*) values were derived, are shown in Table 1.

The measure *tail weight/haul* reflects the return the fishermen obtains from his fishing effort and is therefore regarded as a suitable means of describing changes in relative abundance over a period of time.

The area of investigation formed part of a proclaimed rock lobster sanctuary during the period November 1940 to July 1952. According to the final column of Table I, the level of exploitable stock in the research area was exceptionally high in 1952, i.e. at the end of a period of protection of almost 12 years. As this area lies within immediate

TABLE I: DERIVATION OF CATCH PER UNIT OF EFFORT IN TERMS OF TAIL WEIGHT PER HAUL

Year	Fishing Days	Total No. of Hauls	Total Tail Weight			Tail Weight/ Haul (g) (catch/ unit effort)
			Males (g)	Female (g)	Sexes combined (g)	
1952	35	863	376,730	496,442	873,172	1,012
1953	40	1,160	617,713	401,601	1,019,314	879
1954	19	484	140,004	124,806	264,810	547
1955	16	439	120,338	76,235	196,573	448
1956	13	364	98,036	33,838	131,874	362

reach of boats from both Hout Bay and Cape Town, it is understandable that fishing of high intensity took place here as soon as the legal restrictions were lifted. Table I also shows that, according to the experimental catches, the *catch per unit effort* dropped sharply and consistently from 1952–1956, i.e. during the period of initial heavy exploitation.

Unfortunately no adequate test catch data are available for the period subsequent to 1956, but reports from the industry indicate that rock lobster boats had to start searching further afield as the productivity of this fishing ground declined. Consequently, fishing intensity was also lowered. In August 1960, the area was again proclaimed part of a sanctuary and was, therefore, given complete rest from fishing, until it was re-opened in January 1963. After this period of 29 months, stocks had not recovered sufficiently to make rock lobster fishing profitable. The question arises: how is it possible that an area which is by no means isolated from neighbouring rock lobster grounds, should be depleted so rapidly and should take so long to recover?

If a rock lobster population is relatively static within its habitat, i.e. if little or no mixing with other adult populations takes place, replenishment after heavy exploitation or any other form of mortality can be expected to be slow, as it can only occur by means of larval recruitment. The size composition of the population can only recover by means of individual growth. This process will continue until a biological equilibrium is reached. Unless replenishment of stocks by adult migration is possible, a well-established population can, therefore, be depleted rapidly by fishing of high intensity.

Results of the Division's tagging programme are still to be published but the following figures will give some idea of the magnitude of movements by individuals. Of 170 recoveries of tagged specimens, 103 or 60·5 per cent were found within one mile of the tagging site, recovery time varying from one to 389 days. Only 10 or 5·8 per cent of the recovered specimens had covered more than three miles, with a maximum of eight miles. One specimen was recovered only two miles from the tagging site after 719 days. It appears, therefore, that adult migration is limited in *Jasus lalandii*, and is probably a form of random wandering, rather than a concerted directional movement. This conclusion is confirmed by Bradstock* (1950), who conducted a tagging programme on a closely related species in New Zealand.

Under these circumstances stocks reduced by intense fishing can be expected to take a long time to recover. This is confirmed by the fact that commercial catches in the research area remained poor, even after a closure of 2½ years.

ANALYSIS OF COMMERCIAL CATCH AND EFFORT STATISTICS

For the analysis of commercial catch and effort statistics, rock lobster processing factories were requested to supply the Division with catch records covering as long a period as possible.

Satisfactory data were obtained from only two centres, viz Lamberts Bay and Doring Bay. From these centres catch and fishing effort records were collected for a representative number of boats throughout the period 1955–1964. In addition, records of the total annual landings of all boats operating from each centre were available for the period 1953–1964. Annual catches were expressed in pounds tail weight, while fishing effort was estimated in net-days as follows. The annual fish-

* BRADSTOCK, C. A., 1950. *Zool. Publs Victoria Univ. Coll.* 7: 1–38.

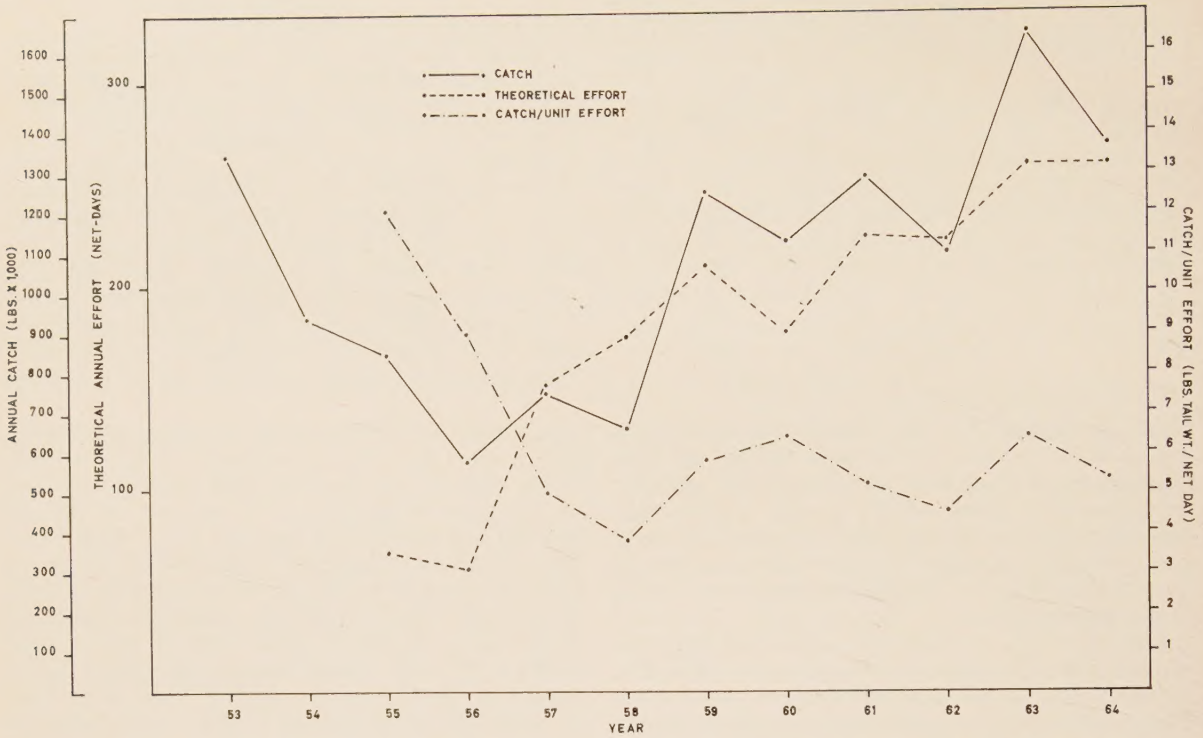


FIG. 3. Fluctuations of annual catch, theoretical annual effort and catch per unit effort, at Lamberts Bay, 1953–1964

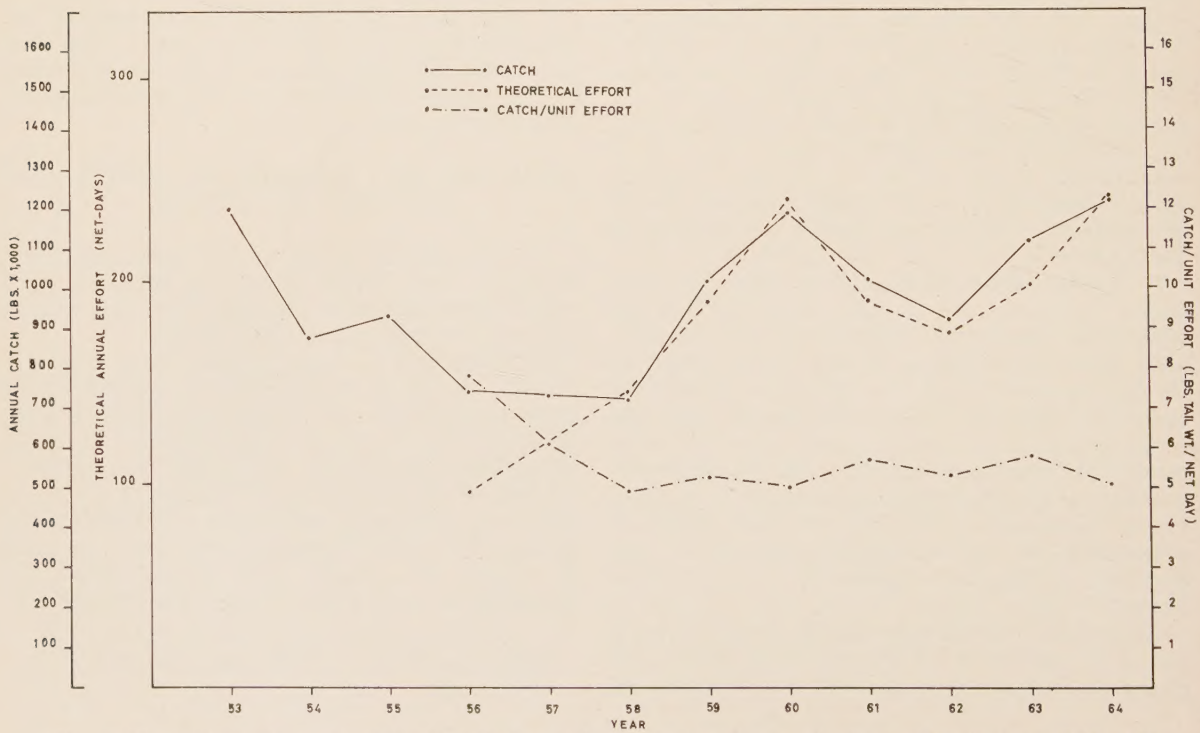


FIG. 4. Fluctuations of annual catch, theoretical annual effort and catch per unit effort, at Doring Bay, 1953–1964

ing effort for particular vessels was calculated from the number of nets carried (which remained constant) and the number of days spent fishing. The total annual effort in a fishing area could then easily be obtained by summing the efforts of individual boats operating in the area. From these two sets of data, the mean annual catch per unit effort, expressed in terms of pounds tail weight per net day, could be calculated.

Lamberts Bay and Doring Bay are two important centres of the South African rock lobster industry. Their combined catch in 1964 amounted to approximately 35 per cent of the total South African west coast landings. In addition, the grounds exploited by the two centres overlap considerably.

The analysis of data obtained from these two centres allowed a description of fluctuations in the relative abundance of rock lobster in the observed areas during the period 1955–1964. As total catch figures were available, the theoretical total effort of the fishing fleets at both centres could be calculated.

Although the course of the fisheries during the observed period can be described adequately, these data do not allow confident predictions of future abundance in the area.

Annual catch and fishing effort data for Lamberts Bay and Doring Bay appear in Tables II and III respectively. In both tables the values in column 4 were calculated from those in columns 2 and 3. Similarly the theoretical total effort estimates appearing in column 6 were calculated from the values in columns 4 and 5. Fluctuations of the variables—annual catch, theoretical annual effort, and annual catch per unit effort—are illustrated for Lamberts Bay and Doring Bay by Figs. 3 and 4 respectively.

Lamberts Bay—Referring to Fig. 3 it will be seen that during the period 1953 to 1956 the annual catch at Lamberts Bay dropped steadily from a value of 1,354,920 lb. tail weight to approximately 50 per cent of this value, viz 588,280 lb. During the period 1955–1957 a very marked decline in catch per unit effort also took place. This decline therefore accompanied the latter part of reduction in the annual catch.

The catch per unit effort values subsequent to 1957 remain relatively constant at about the value for this year. During 1956–1958 the annual catches remained fairly constant at the low level of approximately 650,000 lb. During this period the annual effort increased considerably to maintain these catches in the face of the declining catch per unit effort. In 1959 the catch rose to about 1,250,000 lb. due to both increased effort and an upward fluctuation of catch per unit effort. This catch level was approximately maintained until 1963, when a rise in catch per unit effort, combined with increased annual effort, resulted in a record catch. In 1964 the total catch fell almost to the level occupied during 1959–1962.

To interpret the above trends it is necessary to consider at least the order of magnitude of the catches prior to 1953. Although no figures are available it is reliably reported that the size of the annual catch rose very rapidly in the few years before 1953. This rise was attributed to increased fishing effort. To what level the annual effort rose is unknown, but it can safely be assumed that it was not appreciably above the 1955-1956 level. Under these circumstances a hitherto moderately exploited population might have been subjected to increased fishing effort which would result in a rise in annual

TABLE II: SAMPLED CATCH, FISHING EFFORT, CATCH PER UNIT EFFORT, TOTAL CATCH AND THEORETICAL TOTAL EFFORT FOR LAMBERTS BAY

Year (1)	Sampled catch (lb.) (2)	Sampled effort (net days) (3)	Catch per unit effort (4)	Annual catch (5)	Theoretical annual effort (6)
1953	—	—	—	1,354,920	—
1954	—	—	—	943,920	—
1955	132,110	10,959	12·0549	849,120	70,438
1956	172,275	19,176	8·9839	588,480	65,504
1957	115,295	23,010	5·0106	760,800	151,838
1958	80,945	21,306	3·7992	661,200	174,037
1959	67,830	11,712	5·7915	1,258,680	217,332
1960	80,770	12,624	6·3981	1,136,280	177,596
1961	139,920	26,856	5·2100	1,289,640	247,532
1962	114,080	25,116	4·5421	1,104,369	243,139
1963	176,525	27,480	6·4238	1,653,000	257,324
1964	87,455	16,344	5·3509	1,374,600	256,891

catches, ultimately causing a decline in stocks in the area. The latter part of this decline is indicated by the marked downward trend of catch per unit effort in 1955–1957 and, as has been explained, annual catches in later years could only be maintained at a level approaching that of 1953 by much increased effort.

Doring Bay—Reference to Fig. 4 shows that the annual catch landed at this centre declined during the period 1953–1956, the 1956 value being 62 per cent of that landed in 1953. Unfortunately no estimates of catch per unit effort are available for this period. During 1956–1958 the annual catch remained constant despite the well-defined downward trend of catch per unit effort figures during the period. These catches were therefore only maintained by increasing annual catch effort during 1956–1958. Subsequent to 1958 the catch per unit effort remained constant at about the value for this year and fluctuations in annual catches are therefore closely associated with variations in the annual effort expended. Catch and effort increased during the period 1958–1960, the 1960 catch figure being equivalent to that of 1953. During 1961 and 1962 catch effort was reduced in this area, because of the repatriation of Malawian fishermen working at Doring Bay; the total catch fell accordingly. Increased effort during 1963 and 1964 then resulted in increased catches, the 1964 values for both annual catch and effort being the highest in the series.

Comparison of Fig. 4 with Fig. 3 reveals that the trends of all three variables are similar to those recorded for Lamberts Bay. This is not surprising in view of the overlapping fishing areas exploited by the centres. Exceptions occurred, however, in annual catch and annual effort values for 1961 and 1962 when effort, and accordingly catch, was reduced at Doring Bay.

At both centres the catch per unit effort values remained relatively constant from about 1957 to 1964. In this respect fluctuations about the constant level at Doring Bay occurred less often than at Lamberts Bay.

The interpretation of the fluctuations at Doring Bay is similar to that for Lamberts Bay. Although no estimate of the catch per unit effort for 1955 is available, it can be assumed that the decline in catch was caused by an initial increase in fishing intensity and a subsequent reduction in catch per unit effort. The 1953 catch level was only regained by means of much increased catch effort. Data from Lamberts Bay show that landings in the region of 1,200,000 lb. have been maintained at this centre without causing further significant drops in catch per unit effort. It is uncertain whether this would have been the case at Doring Bay if the 1961 and 1962 effort, and therefore also the catches, had not declined.

Fluctuations in the trends of catch and catch effort have been described for a section of the West Coast fishery. An initial decline in the abundance of stocks at both Lamberts Bay and Doring Bay was followed by a period of fairly constant catch and catch per unit effort. The continuation of these conditions, under which annual catches, effort and catch per unit effort have remained approximately constant would mean that, although the relative abundance of the population has declined, the natural rate of increase of the population has been adjusted and productivity is sufficient to maintain the present annual catches. Under such circum-

TABLE III: SAMPLED CATCH, FISHING EFFORT, CATCH PER UNIT EFFORT, TOTAL CATCH AND THEORETICAL TOTAL EFFORT FOR DORING BAY

Year (1)	Sampled catch (lb.) (2)	Sampled effort (net-days) (3)	Catch per unit effort (4)	Annual catch (5)	Theoretical annual effort (6)
1953	—	—	—	1,203,840	—
1954	—	—	—	874,920	—
1955	—	—	—	930,480	—
1956	170,525	21,967	7·7628	742,560	95,656
1957	234,800	38,245	6·1394	735,720	119,836
1958	234,450	47,753	4·9096	721,440	146,945
1959	488,550	92,147	5·3019	1,014,840	191,411
1960	584,975	116,549	5·0191	1,197,600	238,609
1961	640,600	109,325	5·8592	1,119,600	191,071
1962	604,550	115,103	5·2523	916,680	174,529
1963	678,800	117,865	5·7599	1,146,120	198,983
1964	366,000	72,112	5·0754	1,270,440	250,313

stances the catches could be termed equilibrium catches (Schaeffer, 1957).*

SIZE COMPOSITION OF CATCH

The size composition of rock lobster tails sold on local and overseas markets was analysed for a seven-year period. The object of this analysis was to ascertain whether or not the size composition of the rock lobster population remained constant during this period.

Rock lobster tails to be marketed are graded according to size. Tails of similar size are packed in containers and each container awarded a designation according to the tail size of its contents. These designations, together with details of corresponding pack contents, are shown on Table IV. Containers with the designations from A to G hold a total weight of 20 lb. and the other designations, 10 lb.

Table V is based on information provided by the South African Frozen Rock Lobster Packers (Pty)

TABLE IV: RELATIONSHIP BETWEEN TAIL PACK CATEGORIES AND TAIL WEIGHT

Designation	No. of Tails	Mean Tail Weight	
		oz.	g
A	21—25	14·2	403
B	26—30	11·4	326
C	31—35	9·8	280
D	36—40	8·5	243
F	41—50	7·0	200
G	51—60	5·8	166
H	61—70	5·0	143
J	71—80	4·2	120
M	81—90	3·7	106
S	91—100	3·4	97

TABLE V: FREQUENCY AND FREQUENCY PER CENT OF 20 LB. PACKS PRODUCED DURING THE PERIOD SEPTEMBER, 1957 TO DECEMBER, 1964

Period		PACK DESIGNATION										
		A	B	C	D	F	G	H	J	M	S	Total
1957 58	Frequency ..	26,606	23,609	28,099	38,438	61,435	60,736	48,292	21,816	8,858	254	318,143
	Frequency %	8·363	7·421	8·832	12·082	19·310	19·091	15·179	6·857	2·784	·080	100·0
1959 ..	Frequency ..	12,935	14,682	19,907	34,599	58,793	64,468	63,070	34,656	9,011	8,758	320,879
	Frequency %	4·031	4·576	6·204	10·783	18·322	20·091	19·655	10·800	2·808	2·729	100·0
1960 ..	Frequency ..	9,422	13,637	20,532	39,696	65,735	78,407	84,211	43,508	9,327	22,205	386,680
	Frequency %	2·437	3·527	5·310	10·266	17·000	20·277	21·778	11·252	2·412	5·742	100·0
1961 ..	Frequency ..	7,844	12,386	21,213	40,725	68,520	76,473	75,737	39,187	11,434	10,235	363,754
	Frequency %	2·156	3·405	5·832	11·196	18·837	21·023	20·821	10·773	3·143	2·814	100·0
1962 ..	Frequency ..	4,142	9,153	16,906	30,705	58,540	73,552	71,501	36,221	7,988	588	309,296
	Frequency %	1·339	2·959	5·466	9·927	18·927	23·781	23·117	11·711	2·583	·190	100·0
1963 ..	Frequency ..	7,788	17,181	30,841	48,789	75,734	92,366	86,072	34,112	8,270	3,895	405,048
	Frequency %	1·923	4·242	7·614	12·045	18·697	22·804	21·250	8·422	2·042	·961	100·0
1964 ..	Frequency ..	7,209	17,567	27,818	41,038	68,631	84,708	70,719	30,190	19,342	13,069	380,291
	Frequency %	1·896	4·619	7·315	10·791	18·047	22·275	18·596	7·939	5·086	3·437	100·0

* SCHAEFFER, M. B., 1957. *J. Fish. Res. Bd Can.* 14 (5): 699–681.

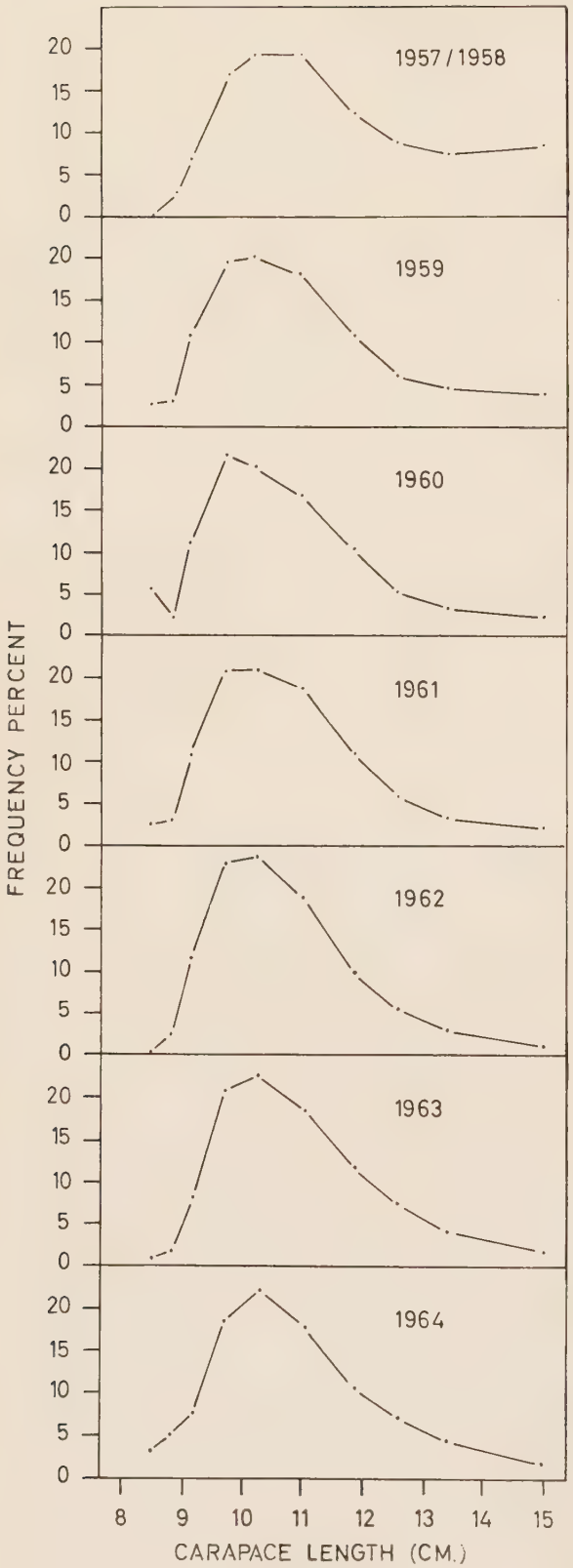


FIG. 5. Size composition of commercial catches 1957–58 to 1964

Ltd (SAFROC), the organisation which co-ordinates the export and marketing of rock lobster products from the Republic and South West Africa. The information supplied consisted of the numbers of 20 lb. and 10 lb. containers of each designation handled by SAFROC during the period September 1957 to December 1964. For the purpose of this analysis, two 10 lb. containers were considered equivalent to one 20 lb. container. The numbers of 20 lb. units and percentages of the total for each period are shown on Table V. It may be assumed in what follows that Table V reflects the whole catch in the area represented by the South African Rock Lobster Fishing Industry, i.e. the rock lobster grounds between the Orange River mouth and Cape Point.

TABLE VI: MEANS OF SIZE FREQUENCY DISTRIBUTIONS

Period	Mean (cm)
1957/58	11·29
1959	10·79
1960	10·58
1961	10·66
1962	10·62
1963	10·80
1964	10·71

The size frequency distribution of catches made within seven periods are considered. The first period includes catches made between September 1957 and December 1958, i.e. 16 months. The reason for this is that the annual catch for 1958 was not recorded separately by the industry and could therefore not be expressed separately from the latter third of 1957. The other periods are full years.

In order to obtain size frequency distributions of rock lobsters within the commercial catches, it was necessary to associate with every designation (A, B, etc.) a measure of rock lobster size. The average tail weight for a given designation was calculated by dividing 20 lb. by the average number of tails—see Table IV. Conversion from mean tail weight to carapace length was then done using the tail weight/carapace length relationship calculated for males and females combined, thus:

$$L_c = 1 \cdot 609 \; W_t^{0 \cdot 3645}$$

where L_c = carapace length in cm

W_t = tail weight in g.

The above relationship was also calculated from

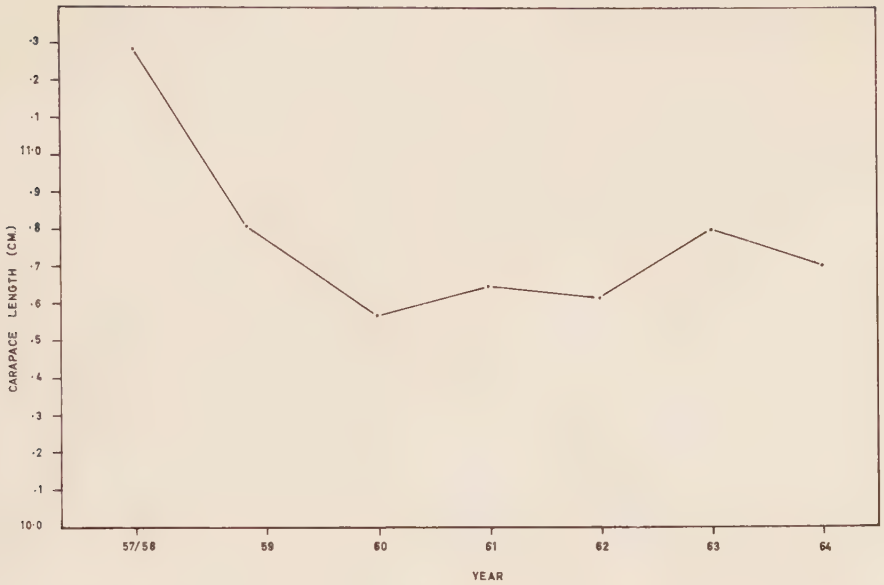


FIG. 6. Mean annual carapace lengths, 1957–58 to 1964

the dimensions of 499 male and 452 female rock lobsters.

Using these mean carapace lengths and the percentages from Table V, the size-frequency distribution of the catch for every period was obtained, and are presented in Fig. 5. The arithmetic means of the size-frequency distributions are shown on Table VI, and plotted on Fig. 6.

To determine whether the differences between the means of these distributions were statistically significant, a test was made. For samples as large as these, sample means are distributed normally, so that differences between the means of the distributions could be tested against the normal distribution, with a pooled estimate of the variance of the difference between two means. The results of such tests were that all the means of the distributions differed significantly from each other at the 1 per cent level. The decline in the average size of rock lobsters caught during the period 1957 to 1960 may therefore be regarded as significant.

Apart from the average size of rock lobster caught, the relative numbers of "small" and "large" animals within each distribution were also considered. Here the designations A and B were taken to represent "large", and M and S "small" animals.

Table VII shows the percentage of the annual total falling into "large" and "small" categories. It is apparent that the percentages in the former category have declined appreciably since 1957–1958.

TABLE VII: PERCENTAGE "LARGE" AND "SMALL" CATEGORIES PACKED DURING RESEARCH PERIOD

Period	Percentage of Total	
	A & B (large)	M & S (small)
1957/58	15·78	2·86
1959	8·61	5·54
1960	5·96	8·15
1961	5·56	5·96
1962	4·30	2·77
1963	6·17	3·00
1964	6·52	8·52

CONCLUSIONS

Mention has been made of an increasing number of requests from sections of the rock lobster industry for concessions with regard to conservational measures. These requests are invariably motivated by complaints of decreasing availability and have originated from various parts of the West Coast.

When discussing the implications of the above requests, it is important to bear in mind that total catches have remained constant since 1942. This is due to a rigidly enforced annual export quota system which limits the catch to approximately 7,000,000 lb. per annum. Theoretically, therefore, a decline in catch per unit effort should not have taken place in recent years if the stocks had been

capable of coping adequately with the above catch figure.

The present investigation was undertaken to ascertain whether the complaints of decreasing availability could be confirmed by an analysis of available catch statistics. In the course of this analysis it was shown that a reduction in availability associated with high fishing intensity definitely occurred in the restricted Duiker Point to Logies Rock area during the period 1952–1956. In addition, catch statistics from Lamberts Bay and Doring Bay (an area which contributes about 35 per cent of the total West Coast catch), revealed a decline in stocks during 1955–1958, followed by a six-year period of more or less constant catch per unit effort. Finally, an analysis of tail pack categories showed a decrease in the mean size of rock lobsters caught during the period 1958–1960 along the whole West Coast. This was followed by a four-year period (1961–1964) during which the mean size fluctuated fairly constantly around that attained in 1960.

It is acknowledged that the areas from which sufficient catch statistics were available and those from which complaints have originated, do not necessarily coincide, and that the above evidence indicating overall changes in the availability of West Coast stocks is therefore incomplete. Nevertheless it is striking that all three methods of investigation have indicated a marked decline in availability in various areas and at various times, and that no similarly well defined upward trend has been found.

It would appear, therefore, that the above-mentioned complaints have not been made without reason, and that it is unrealistic to assume that concessions with regard to conservational measures would compensate over a long term for decreasing availability. Reduction of the present minimum size limit or the allocation of additional or increased quotas, must increase pressure on this resource. This must be avoided, because a further decline in availability could place the whole industry in an extremely awkward position.

DIATOMS IN THE APHOTIC ZONE OF THE SOUTH-WEST INDIAN OCEAN

E. A. Nel

Diatoms, because of their utilization of light as a source of energy for photosynthesis, have always been considered as organisms living only in the upper layers of the sea where enough light penetrates. This photic or light zone is about 100–200 m deep in the open oceans, and within the upper 50–80 m, known as the euphotic zone, most species find their optimum light conditions. The photic zone varies considerably in depth during the day and night; it also varies seasonally and geographically. Below this zone is the aphotic zone, where temperatures are low and no light penetrates.

In recent years, several workers have recorded the presence of live photosynthetic organisms down to 1,000 m and even 3,000 m, i.e. well beyond the lower limit of the photic zone.

Bernard and Lecal (1960)* and Bernard (1964)** recorded the presence of fairly large numbers of chlorophyll-containing micro-organisms, mainly Myxophyceae and *Cyclococcolithus*, at depths of 1,000 m and 3,000 m in the Indian and Atlantic Oceans and the Mediterranean.

Kimball, Corcoran and Wood (1963)† used Van Dorn bottles and a modified J–Z sampler to obtain samples from 900 m to 3,000 m in the Atlantic and Pacific Oceans, and found fairly large numbers of diatoms at those depths, all of which contained chlorophyll and were thus taken to be alive when caught. The J–Z sampler is a collapsed polythene bottle which is lowered until the appropriate depth is reached, where the external pressure breaks the collecting tube, the bottle expands and the sample of water is sucked into it. This prevents contamination from other levels. At one station they recorded a much greater population at 900 m in the aphotic zone than at 150 m in the euphotic zone, which rendered it highly improbable that the sample from 900 m had been contaminated from the euphotic zone.

These workers produced cultures from samples of diatoms taken at great depths, further proof that the diatoms were alive when caught. From 3,000 m they recorded, amongst others, *Thalassiothrix* sp. and *Hemiaulus hauckii*.

Ohwada (1960)‡ took samples with a Nansen bottle at ten different depths down to 1,000 m in the Pacific Ocean, off the east coast of northern Japan. He recorded the presence of live diatoms down to 1,000 m, but found the euphotic zone much more productive than the aphotic zone. Although most of the diatoms in his samples from below 500 m were dead cells, he recorded fair numbers (about 20 per cent of the total diatoms in a particular sample) of live *Coscinodiscus* spp. at 600 m and live *Biddulphia aurita* at 800 m at the same station in the Tsugaru Warm Current.

Wood and Kimor (1966)§ used Van Dorn bottles and closing-nets to obtain samples from the aphotic zone in the Mediterranean Sea. They recorded large populations of *Halosphaera viridis* in the closing-net samples collected at different intervals of depth between 3,000 m and 500 m. The specimens obtained from their samples appeared to have been alive when caught by the net, as was shown by the fluorescent technique of Wood (1955, 1962),¶ whereby photosynthetic organisms show a characteristic red glow. Large numbers of *Ceratium carriense* var. *volans* were found down to 4,000 m, whereas the deepest diatom recorded by them was *Coscinodiscus centralis* from a horizontal sample taken at 500 m (Wood and Kimor, 1966).

During the October 1965 cruise undertaken by the Division of Sea Fisheries, ten samples were taken with a Munro-Eckman bottle at 600 m and 1,500 m at stations 140 miles and 200 miles off the south-east coast of South Africa. Live diatoms, sometimes in fair numbers, were found in all these samples. At one station, about 180 miles south-west of the Cape of Good Hope, the amount of phytoplankton from 1,500 m was about four times larger than that from 600 m, and the two samples contained different species of diatoms. These samples were taken as a check on the more copious data presented below, which were obtained earlier from a more contentious source, viz deep closing-net catches.

During 1961–1963, the Division of Sea Fisheries undertook three cruises in the South-west Indian Ocean. Fig. 7 is a track chart of these cruises. The phytoplankton in the euphotic zone was

* BERNARD, F. and J. LECAL 1960. *Bull. Inst. Océanogr. Monaco* 1166: 1–59.

** BERNARD, F. 1964. *Pelagos*, Alger, 2 (2): 1–32.

† KIMBALL, J. F., CORCORAN, E. F. and E. J. F. WOOD 1963. *Bull. mar. Sci. Gulf Caribb.* 13 (4): 574-577.

‡ OHWADA, M. 1960. *Bull. Hakodate mar. Obs.* 7: 1–5.

§ WOOD, E. J. F. and B. KIMOR 1966. Communication presented in 1966 at the Moscow Oceanographic Congress.

¶ WOOD, E. J. F. 1955. *J. Cons. perm. int. Explor. Mer* 21 (1): 6–7.

¶ WOOD, E. J. F. 1962. *Limnol. Oceanogr.* 7 (1): 32–35.

TABLE I: STATION POSITIONS AND SAMPLES ANALYSED FROM EACH STATION

Ships Station No.	Station Reference No.	Position	N70V Closing-net Depths			
			750—500 metres	1,000—750 metres	1,500—1,000 metres	3,000—1,500 metres
A1227	4	26° 09′ S; 34° 30′ E	D	—	—	—
A1228	5	26° 08′ S; 35° 06′ E	D	—	—	—
A1229	6	26° 12′ S; 36° 12′ E	D	D	D	—
A1330	7	26° 42′ S; 37° 41′ E	D	D	D	—
A1232	9	27° 10′ S; 41° 45′ E	D	—	—	—
A1233	10	27° 22′ S; 43° 35′ E	D	D	D	—
A1234	11	27° 47′ S; 45° 41′ E	D	D	D	—
A1235	12	27° 48′ S; 47° 19′ E	D	D	D	—
A1236	13	28° 11′ S; 49° 20′ E	D	D	D	D
A1237	14	29° 29′ S; 50° 30′ E	D	D	D	D
A1238	15	30° 50′ S; 51° 36′ E	D	D	D	—
A1239	16	32° 07′ S; 52° 49′ E	D	D	D	D
A1242	19	26° 16′ S; 56° 21′ E	D	D	—	—
A1244	21	33° 24′ S; 55° 32′ E	D	D	D	—
A1245	22	36° 16′ S; 56° 45′ E	D	D	—	—
A1246	23	37° 56′ S; 58° 03′ E	D	D	D	—
A1247	24	37° 17·5′ S; 54° 36′ E	D	D	D	—
A1249	26	36° 31′ S; 51° 10′ E	D	D	D	—
A1250	27	35° 55′ S; 48° 06′ E	D	D	D	—
A1251	28	35° 04′ S; 44° 17′ E	D	D	—	—
A1252	29	34° 17′ S; 40° 46′ E	D	D	D	—
A1253	30	33° 35′ S; 37° 51′ E	D	D	D	—
A1254	31	33° 01′ S; 34° 49′ E	D	D	—	—
A1877	35	40° 44′ S; 33° 36′ E	D	D	D	—
A1878	36	43° 07′ S; 34° 57′ E	D	D	—	—
A1880	38	45° 25′ S; 36° 32′ E	D	D	D	—
A1883	41	45° 16′ S; 40° 41′ E	D	D	—	—
A1885	43	44° 44·5′ S; 47° 24′ E	D	D	D	—
A1887	45	43° 38′ S; 49° 20′ E	D	D	D	—
A1889	47	41° 37′ S; 47° 14′ E	D	D	D	—
A1890	48	39° 41′ S; 44° 56′ E	D	D	D	—
A1891	49	37° 42′ S; 42° 38′ E	D	D	D	—
A1892	50	36° 28′ S; 41° 22′ E	D	D	D	—
A1893	51	36° 16·5′ S; 38° 37′ E	—	—	D	—
A1894	52	36° 02′ S; 35° 38′ E	D	D	D	—
A1896	54	34° 12′ S; 28° 24′ E	D	D	D	—
A2386	56	36° 33′ S; 20° 01′ E	D	—	—	—
A2387	57	37° 36·5′ S; 19° 34·5′ E	D	D	D	D
A2388	58	39° 01′ S; 20° 04′ E	D	D	D	D
A2390	60	40° 18′ S; 20° 26′ E	D	D	D	D
A2391	61	41° 58·8′ S; 21° 59′ E	D	D	D	D
A2392	62	43° 22′ S; 24° 04′ E	D	D	D	D
A2394	64	44° 40′ S; 26° 05′ E	D	D	D	D
A2396	66	47° 03′ S; 30° 05′ E	D	D	—	—
A2398	68	46° 59′ S; 35° 11′ E	D	D	D	—

D = Closing-net done and sample analysed. — = No closing-net sample taken.

sampled by means of N5OV net hauls (100–0 m or 50–0 m) and a series of samples taken with a Nansen-Pettersson water-sampler from standard depths between 0 m and 150 m. These results have been presented in a separate report (Nel, 1968).*

Apart from other biological sampling, a number of N70V closing-net hauls were done at various stations. While examining the zooplankton sampled from depths far below the penetration of light, the presence of numerous phytoplankton organisms was noted. A total of 127 samples, taken at 45 different stations on the Indian Ocean cruises, were examined for the presence of phytoplankton in the aphotic zone. These were taken at the following intervals of depth: 3,000–1,500 m, 1,500–1,000 m, 1,000–750 m and 750–500 m. Table I gives a list of the stations, their positions and the samples analysed from each station.

These deep-water samples were examined under

* NEL, E. A. 1968. *Investl Rep. Div. Sea Fish. S. Afr.* 62: 1–178.

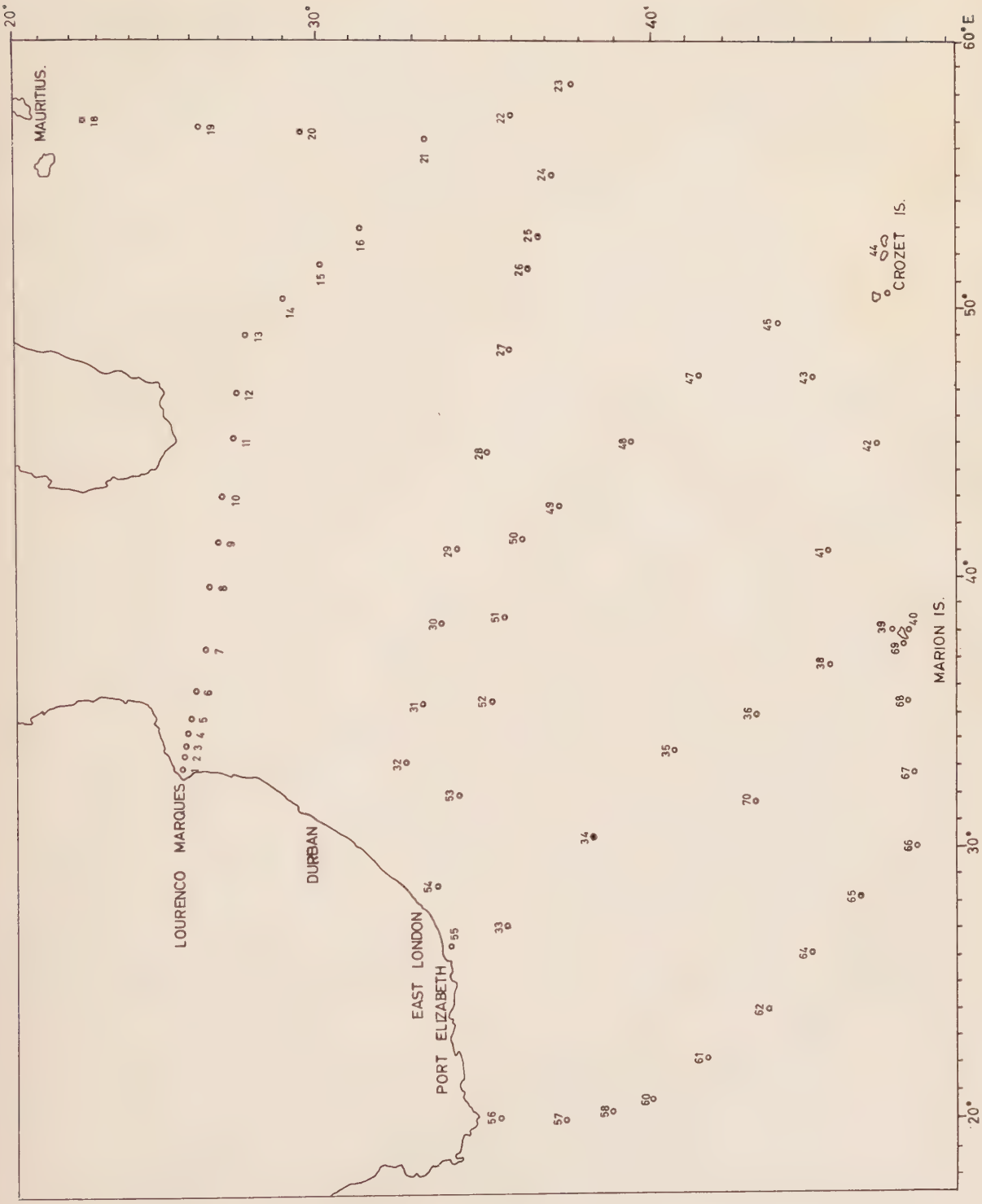


FIG. 7. Positions of Stations in area investigated during 1961, 1962 and 1963

high power of a dissecting microscope (100×) and, where possible, the species were identified. Some of the organisms that can only be identified to species under 1,000× or 2,000× magnifications were identified to genera. In each case the entire sample was examined, and a list made of the genera or species of diatoms, dinoflagellates and other microplankton present. Notes were made on the total quantity of diatoms which were present in the sample, on the relative amount of each species present in the sample, and on whether each diatom appeared to have been alive or dead when caught. Live diatoms were taken to be those with normal chromatophores, whereas those with shrunken chromatophores or empty shells were taken as dead (Ohwada, 1960).

The purpose of examining the samples from below 500 m was not to find out exactly which species were present, but to try to ascertain whether any live phytoplankton existed at all in those depths.

Table III gives a complete list of the species recorded, their distribution and relative abundance in each sample at every station. A total of 72 species of microplankton were recorded from these deep-water samples, 48 being diatoms, 14 dinoflagellates and 10 representing other groups of microplankton. The dinoflagellates and the zooplankton micro-organisms were known to live in the deeper areas of the oceans (Haeckel, 1887; Belyaeva, 1962).*

Large amounts of phytoplankton, mainly diatoms, were found below 500 m. The relative amounts of phytoplankton present in the samples were plotted on maps, one for each interval of depth (Figs. 8–11). It was found that, during the 1961 cruise which covered an area nearer the Tropics, the samples from the aphotic zone were richer in diatoms than those taken in corresponding depths during the 1962 cruise which extended further south, both these cruises having been done in the winter. The samples of the 1963 cruise, also in the south, but undertaken in the autumn, were very rich in diatoms from the deep waters.

Some of the species recorded from below 500 m have also been found at the same depths by other workers. *Thalassiothrix* sp. and *Hemiaulus hauckii* which were present in our samples from 3,000–1,500 m (Table III), were recorded from 3,000 m by Kimball, Corcoran and Wood (1963). *Halosphaera viridis*, which was found at different intervals of depth between 3,000 m and 500 m by Wood and Kimor (1966), was also present at a number of stations between 500 m and 3,000 m (Table III).

In some cases, especially at Stations 10, 11, 19, 57, 60 and 64 (Fig. 7), the amount of phytoplankton in the aphotic zone exceeded the amount found in the euphotic zone. The great majority (70-80 per cent) of these diatoms from the aphotic zone appeared to have been alive when caught by the net. It can be seen from Table II that 80 per cent of the samples analysed contained live diatoms.

TABLE II: PERCENTAGE HAULS AT EACH DEPTH CONTAINING LIVE DIATOMS

Depth Metres	Total No. Samples	No. Containing Live Diatoms	% Hauls Containing Live Diatoms
3,000—1,500 ..	9	8	88·88
1,500—1,000 ..	34	26	76·47
1,000—750	40	31	77·50
750—500	44	37	84·09

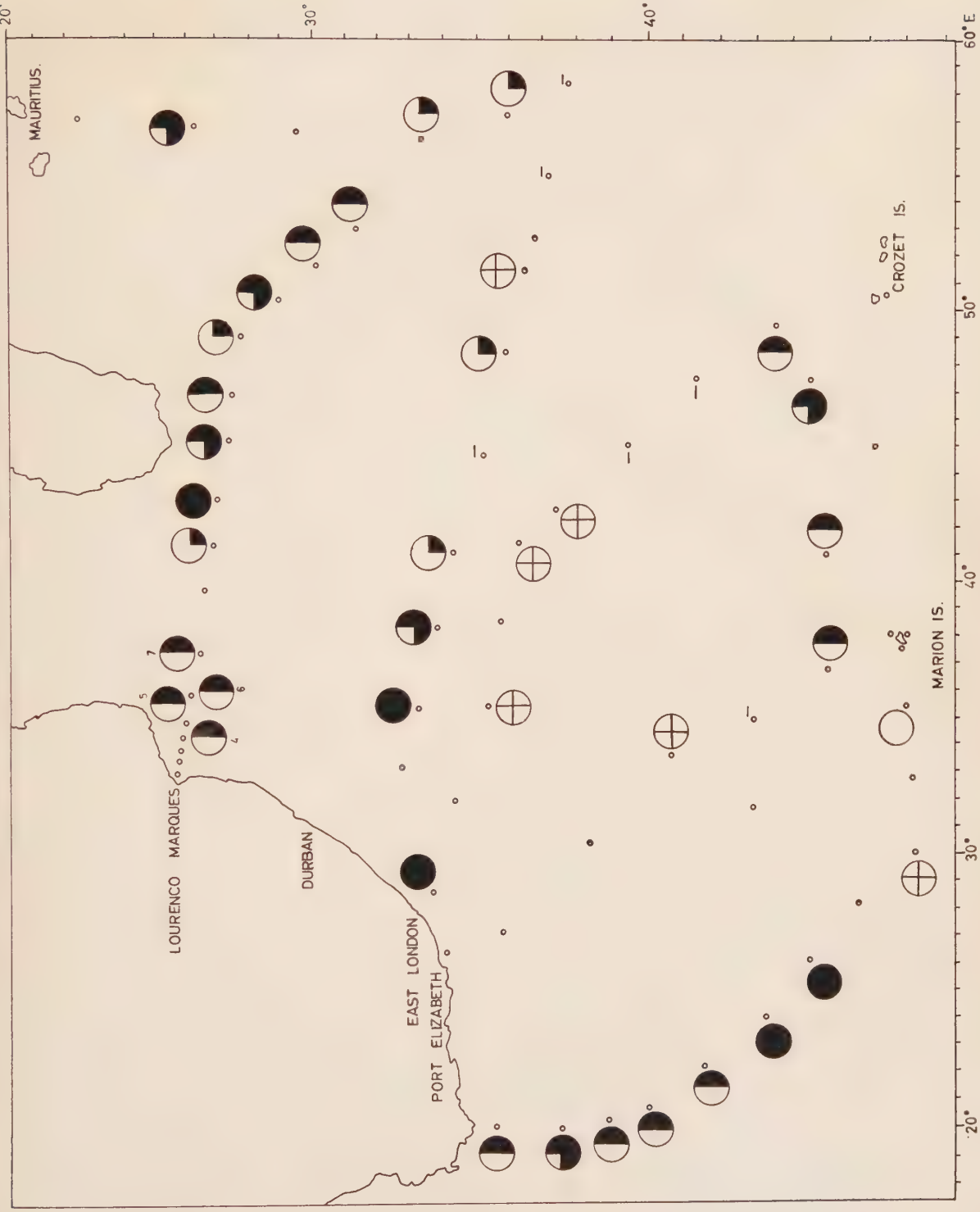
% Total Hauls containing live Diatoms = 80·3%

At first the possibility that these diatoms could have been caught in the meshes of the net in the euphotic zone either on the way down or up, was considered. Various factors, however, seemed to indicate that contamination of the samples in the euphotic zone was highly unlikely:

(*a*) The shape and structure of the diatoms: Many of the diatoms, such as *Chaetoceros* spp., possess long spines or setae as an aid to flotation, which would be broken off or damaged when forced through the meshes

* HAECKEL, E. 1887. "*Challenger*" *Rep.* 18: 1–1803.
BELYAEVA, N. V. 1962. *Mosk. Obschch. Ispytat. Prirody, Otd. Geol.* 37 (3): 98–101.

Key to Figs. 8–11:
— = No Diatoms
○ = Dead Diatoms only
⊕ = Few live Diatoms (1–40 cells)
◔ = Few dead + few live Diatoms (41–80 cells)
◑ = Mostly live Diatoms (81–120 cells)
◕ = Fair number of Diatoms (121–200 cells)
● = Large number of Diatoms (more than 200 cells)



FIGS. 8–11 show the relative amounts of phytoplankton present in the N70V samples, one for each interval of depth. An idea is also given of the amount of live Diatoms present in the sample

FIG. 8. 750–500 m

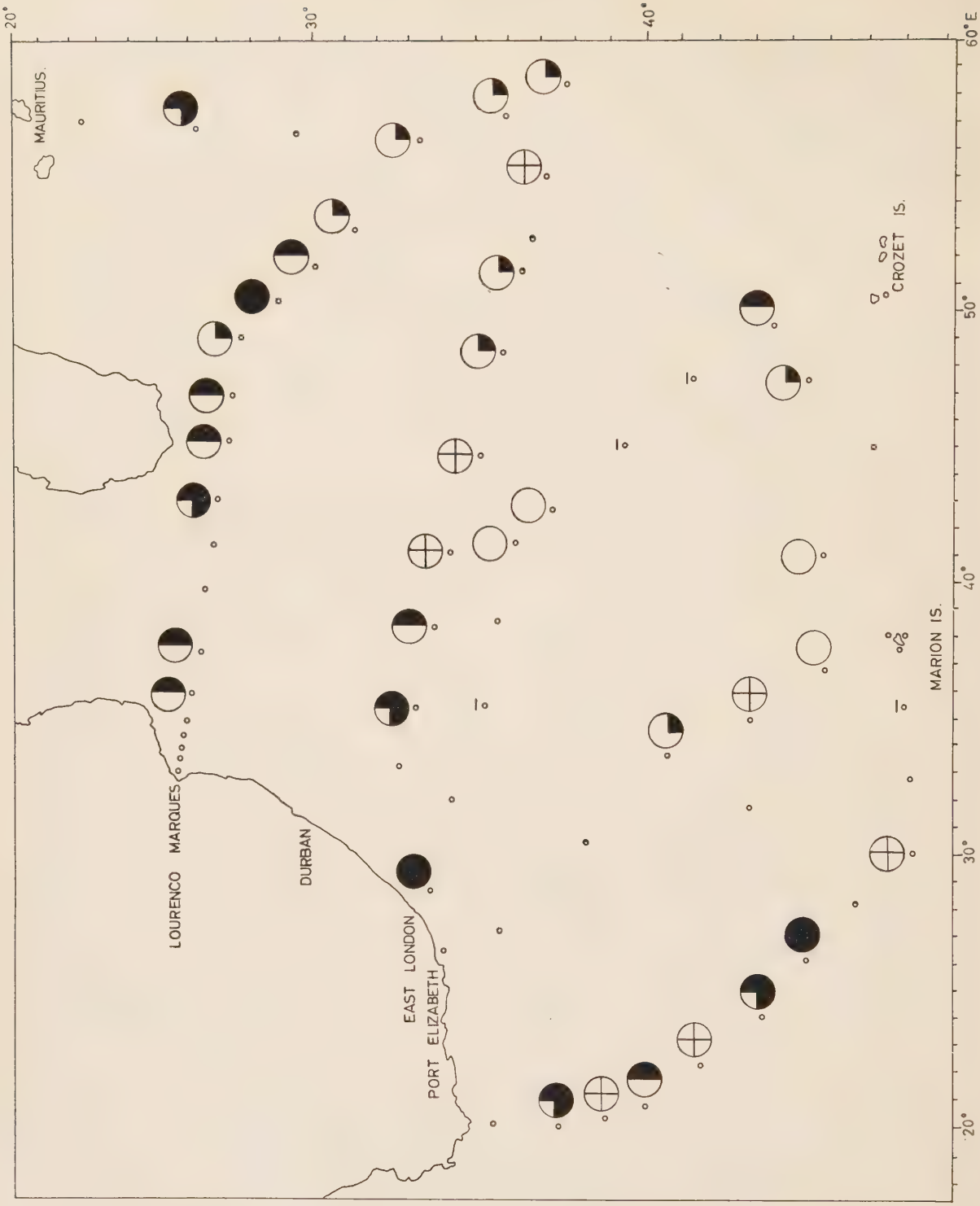


FIG. 9. 1,000–750 m

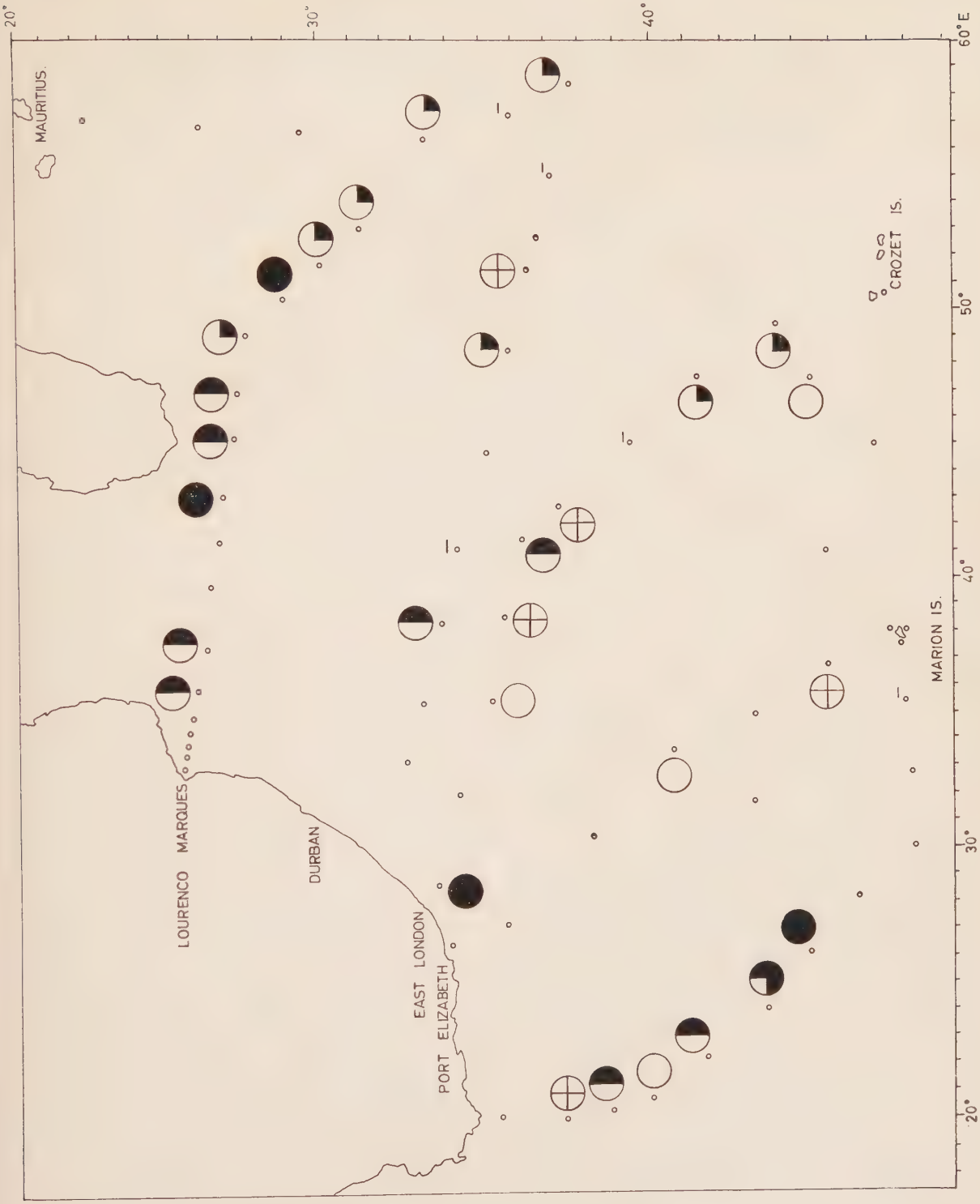


FIG. 10. 1,500–1,000 m

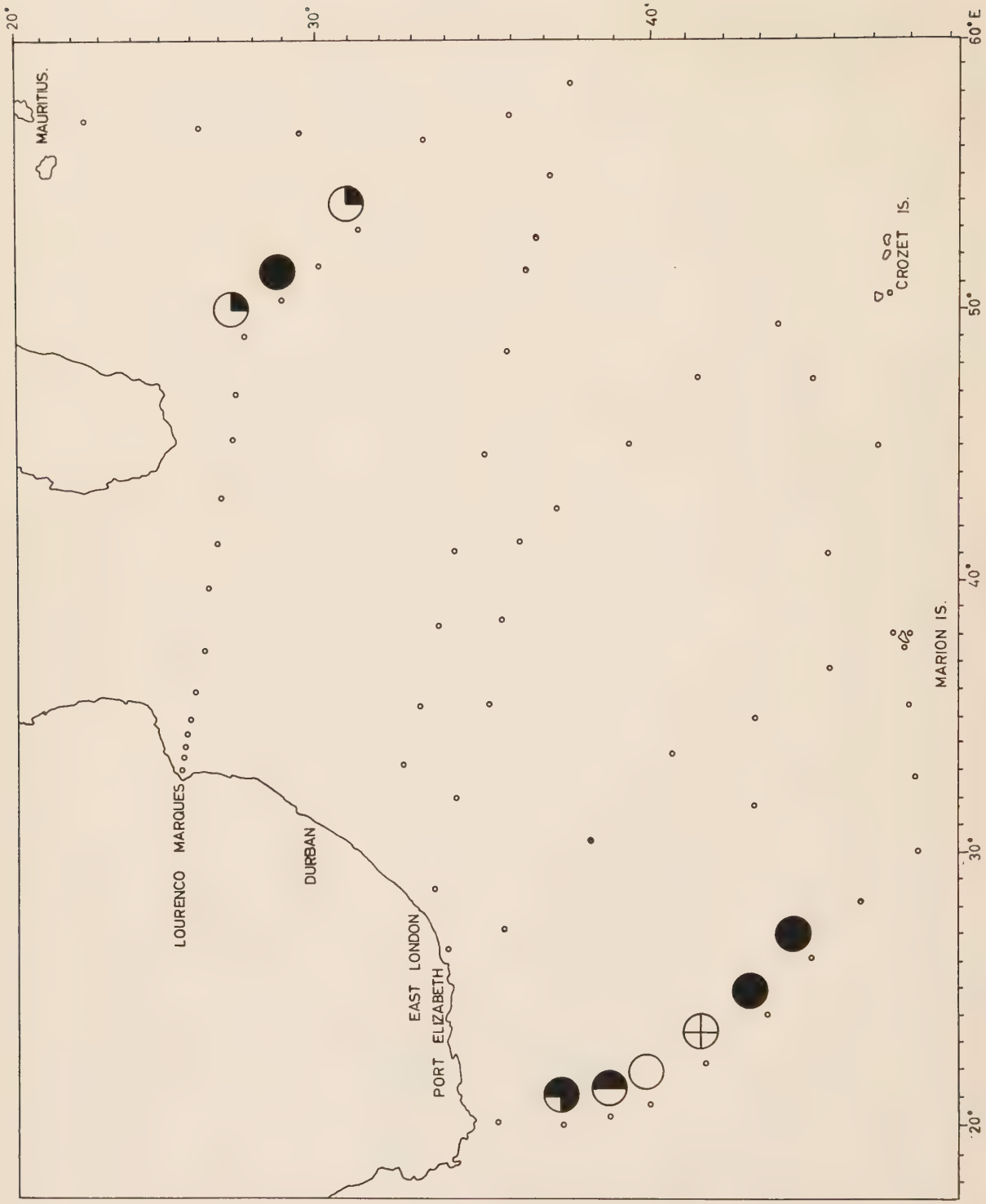


FIG. 11. 3,000–1,500 m

of the net. The specimens observed, which included large numbers of *Chaetoceros* spp., were intact. This proves that they were caught by the net at the actual sampling depth.

(*b*) The size of the diatoms:

Although some species, e.g. *Thalassiothrix* spp., are only a fraction of a millimetre in diameter, but up to 1 mm in length, they would only pass through the meshes of the net if they were "end-on" to the openings, and did not lie across the meshes. There is a chance that a few might have been at a favourable angle to do so, but this would not account for the large numbers found in the samples from the aphotic zone, especially when that particular species was not abundant in the euphotic strata at the same station. Certain species are larger than the mesh sizes of the N70V net, and thus cannot pass through the meshes unharmed.

At some stations in the South-west Indian Ocean, the diatoms that occurred in very large numbers below 500 m were not abundant in the upper 150 m, and in some cases were actually not present in either the N50V net or Nansen-Pettersson samples from that station. This was the case at two stations (62 and 64) just south of the Subtropical Convergence, 600 miles south of Port Elizabeth, where *Thalassiothrix* spp. were very numerous in the deep waters from 3,000 m to 500 m, whereas specimens of *Nitzschia delicatissima* mostly accounted for the large amounts of phytoplankton in the euphotic zone.

At Station 11, just south of Madagascar, *Chaetoceros* spp., *Bacteriastrum* spp. and *Rhizosolenia stolterfothii* were most abundant in the upper 150 m, while *Hemiaulus membranaceus* was present in fairly large numbers in the waters below 500 m.

At Station 13, *Rhizosolenia castracanei* was most abundant below 500 m, while in the euphotic zone *Chaetoceros* spp. and *Hemiaulus hauckii* predominated.

At Station 21, where there was little phytoplankton in the euphotic zone, fair numbers of *Chaetoceros* spp. were present in the aphotic zone. No *Chaetoceros* spp. were recorded from the upper 100 m.

At Station 24 only *Rhizosolenia bergonii* was present in the deep waters, while other species such as *Chaetoceros* and *Dactyliosolen mediterraneous* were abundant in the upper 150 m.

At Station 41 *Thalassiothrix* spp. were present in fair numbers in the samples taken from 750–500 m, absent in the samples from below 750 m, and only recorded in small numbers at 10 m in the euphotic zone.

Rhizosolenia curva was the most abundant diatom in the deep waters at Station 43, but was not recorded from the euphotic zone there.

At Station 49, where no diatoms were recorded in the samples from the upper 150 m, various species of *Rhizosolenia* were found from 1,500 m to 500 m.

At Station 60 a large amount of *Thalassiothrix* spp. was recorded in the sample from 1,000–750 m and a fair number of *Rhizosolenia* spp. from 750–500 m, whereas *Nitzschia delicatissima* and *Pseudoeunotia doliolus* were the predominant diatoms in the samples from the upper 150 m.

Although in some cases the same diatoms were abundant in the samples from both the aphotic and euphotic zones, there were a number of stations, as can be seen from the above data, where completely different species of diatoms were abundant in the two zones. So it seems that there are at least two different communities of diatoms living and producing in the two zones in the ocean. The most common and abundant diatoms found in the waters below 500 m were *Chaetoceros* spp., *Rhizsolenia* spp. and *Thalassiothrix* spp. Since these chlorophyll-containing micro-organisms live in the deep layers of the oceans, they can appreciably add to the general biomass of primary production of the oceans.

Danforth (1962)* states that "there is a great deal of evidence that the 'dark metabolism' of photosynthetic plants, including the algae, is essentially similar to that of non-photosynthetic organisms". Therefore certain substrates can function as carbon and energy sources, and can substitute for photosynthesis. This heterotrophic growth is known to occur in a large number of bacteria at great depths in the oceans, and it seems that other micro-organisms are also heterotrophic at times.

* DANFORTH, W. F. 1962. In *Physiology and Biochemistry of Algae*. ed. R. A. Lewin: 99–123.

Key to Table III.

r = 1 — 20 cells. f = 21 — 40 cells. + = 41 — 80 cells. c = > 80 cells.

• = Alive when caught } Applies to Diatoms only.
○ = Empty or dead cells }

TABLE III: SPECIES LIST, DISTRIBUTIO

STATION NUMBE

SPECIES	Depth Metres	4	5	6	7	9	10	11	12	13	14	15	16	19	21	22
DIATOMS																
Bacteriastrum minus	750—500															
	1,000—750															
	1,500—1,000															
	3,000—1,500															
Bacteriastrum species	750—500															
	1,000—750															
	1,500—1,000															
	3,000—1,500															
Chaetoceros aequatoriale	750—500						r•									
	1,000—750			r•										r•		
	1,500—1,000						r•									
	3,000—1,500															
Chaetoceros affinis var. *circinalis*	750—500															
	1,000—750						r•									
	1,500—1,000															
	3,000—1,500															
Chaetoceros "*affinis* var. *perpusillus*"	750—500												r○			
	1,000—750															
	1,500—1,000															
	3,000—1,500															
Chaetoceros atlanticus	750—500															
	1,000—750						r•		r•							
	1,500—1,000															
	3,000—1,500															
Chaetoceros coarctatus	750—500							r•						r•		
	1,000—750			r•	r•									r•		
	1,500—1,000			r•							r•					
	3,000—1,500										r•					
Chaetoceros densus	750—500															
	1,000—750															
	1,500—1,000															
	3,000—1,500															
Chaetoceros lorenzianus	750—500						r•									
	1,000—750															
	1,500—1,000						r•									
	3,000—1,500															
Chaetoceros messanensis	750—500															
	1,000—750						r•									
	1,500—1,000															
	3,000—1,500															
Chaetoceros peruvianus	750—500				r•	r•	r•	r•						r•		
	1,000—750			r•	r•		r•	r•	r•			r•	r○	r•		
	1,500—1,000			r•	r•		r•		r•							
	3,000—1,500															
Chaetoceros tetrastichon	750—500															
	1,000—750			r•												
	1,500—1,000				r•										r•	
	3,000—1,500															

* Key on page 19.

ND RELATIVE ABUNDANCE OF THE SPECIES *

: 1961—1963 CRUISES

24	26	27	28	29	30	31	35	36	38	41	43	45	47	48	49	50	51	52	54	56	57	58	60	61	62	64	66	68
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		r∘			r•	r•						r•							r•			r•	r•					
					r•		r∘												r•			r•			r•			
																						r•			r•			

TABLE III: SPECIES LIST, DISTRIBUTIO

STATION NUMBE

SPECIES	Depth Metres	4	5	6	7	9	10	11	12	13	14	15	16	19	21	22	2
Chaetoceros species	750—500		r•	r•		r○	c•	+•	r•				r•	r•	r•		
	1,000—750			r•			+○•	r•	f•		r•		r•	r•	r○•	r○	
	1,500—1,000			r○	r○		c•	r•	f•						r○•		
	3,000—1,500									r•	r•						
Climacodium frauenfeldianum	750—500	r○															
	1,000—750			r•				r○	r•			r•					
	1,500—1,000			r○				r○									
	3,000—1,500																
Corethron criophilum	750—500																
	1,000—750																
	1,500—1,000																
	3,000—1,500																
Dactyliosolen species	750—500				r○		r○							r°			
	1,000—750								r○								
	1,500—1,000																
	3,000—1,500																
Ditylum sol	750—500																
	1,000—750																
	1,500—1,000						r○										
	3,000—1,500																
Fragilaria species	750—500																
	1,000—750																
	1,500—1,000																
	3,000—1,500																
Gossleriella tropica	750—500		r•	r•	r○		r•	r•				r•					
	1,000—750							r•	r○			r•					
	1,500—1,000							r•				r•			r•		
	3,000—1,500									r○			r○				
Guinardia flaccida	750—500																
	1,000—750																
	1,500—1,000																
	3,000—1,500																
Hemiaulus hauckii	750—500										+•		r•	c•			
	1,000—750										c•	r•		c•			
	1,500—1,000							r•		r•	c•	r•	r•				
	3,000—1,500										c•		r○				
Hemiaulus membranaceus	750—500							f•									
	1,000—750							r•									
	1,500—1,000							r•									
	3,000—1,500																
Hemiaulus sinensis	750—500					r•											
	1,000—750																
	1,500—1,000																
	3,000—1,500																
Nitzschia species	750—500						r○										
	1,000—750																
	1,500—1,000																
	3,000—1,500																

ND RELATIVE ABUNDANCE OF THE SPECIES (continued)

: 1961—1963 CRUISES.

24	26	27	28	29	30	31	35	36	38	41	43	45	47	48	49	50	51	52	54	56	57	58	60	61	62	64	66	68
	r•	r•		r•	+•	+•						r•							f•	f•	f•	r•	r•	r•	r•	r•		
	r•	r•		r•	+•	+•						r∘							c•		r•		r∘					
	r•	r•			f•		r∘					r∘				f•			c•			r•						
																					r•	r•			r•			
																					r•			r•				
																					r•							
																					r•							
												r•													+•	r•		
																									f•			
																									+•	+•		
																									+•			
										r																		
																											r∘	
		r•			r•	r•															r•							
						r•															r•							
		r•																										
																					r•	r•						
																								r•				
																		r∘										

TABLE III: SPECIES LIST, DISTRIBUTIO

STATION NUMBE

SPECIES	Depth Metres	4	5	6	7	9	10	11	12	13	14	15	16	19	21	22	2
Planktoniella sol	750—500	r•														r○	
	1,000—750										r•						
	1,500—1,000										r○						
	3,000—1,500																
Pseudoeunotia doliolus	750—500						r•										
	1,000—750																
	1,500—1,000																
	3,000—1,500																
Rhabdonema species	750—500													r○			
	1,000—750																
	1,500—1,000																
	3,000—1,500																
Rhizosolenia acuminata	750—500							r•		r•							
	1,000—750										r•						
	1,500—1,000																
	3,000—1,500									r○							
Rhizosolenia alata	750—500							r•									
	1,000—750																
	1,500—1,000																
	3,000—1,500																
Rhizosolenia bergonii	750—500	r•					r•						r•			r•	
	1,000—750																
	1,500—1,000														r•		
	3,000—1,500										r•						
Rhizosolenia calcar-avis	750—500								r•								
	1,000—750																
	1,500—1,000																
	3,000—1,500																
Rhizosolenia castracanei	750—500			r•	r•			r•	r•	r○	r•						
	1,000—750			r•	r•					f•	f•			f•			
	1,500—1,000			r○						f○	f•						
	3,000—1,500									f•	r•						
Rhizosolenia curva	750—500																
	1,000—750																
	1,500—1,000																
	3,000—1,500																
Rhizosolenia imbricata	750—500																
	1,000—750			r•													
	1,500—1,000																
	3,000—1,500																
Rhizosolenia robusta	750—500							r•									
	1,000—750																
	1,500—1,000																
	3,000—1,500																
Rhizosolenia setigera	750—500																
	1,000—750																
	1,500—1,000							r○									
	3,000—1,500																

ID RELATIVE ABUNDANCE OF THE SPECIES (continued)

: 1961—1963 CRUISES

4	26	27	28	29	30	31	35	36	38	41	43	45	47	48	49	50	51	52	54	56	57	58	60	61	62	64	66	68
																r○												
																							r•			r•		
	r•				r•					r•	r○	r°				r•										r•		
	r•				r•		r○					r•																
		r•							r•										r•			r•			f•			
																									r•			
						r•			r•	r•													r•		r•	r•		
•						r•															r•					r•		
																										r•		
																							r○		r•	r•		
									r•	r•	f•																r•	
											r•																	
											r○	r•																
						r•									r•			r•	r•		r•			r•	r•			
																					r•				r•			
															r•	f•			r○									

TABLE III: SPECIES LIST, DISTRIBUTIO

STATION NUMBE

SPECIES	Depth Metres	4	5	6	7	9	10	11	12	13	14	15	16	19	21	22	2
Rhizosolenia simplex	750—500																
	1,000—750																
	1,500—1,000																
	3,000—1,500																
?*Rhizosolenia* species	750—500							r•									
	1,000—750																
	1,500—1,000																
	3,000—1,500																
Rhizosolenia species	750—500	r•	r•	f•○			+•○		f•○			r•	r•		r○		
	1,000—750				r•			r•	r•	r○	r•	r•	r•	r○	r•	r•○	
	1,500—1,000			r•	r•○		f•○	r•○	f•	r○	r•	r•			r•		
	3,000—1,500									r○			r•				
Rhizosolenia stolterfothii	750—500																
	1,000—750																
	1,500—1,000																
	3,000—1,500																
Rhizosolenia styliformis	750—500		r•		r•	r•	r•	r•		r•	r•○	r•	r•	r○			
	1,000—750			r•	r•		r•	r•			r•			r○			
	1,500—1,000			r•				r•			r•		r•				
	3,000—1,500									r•	r•		r•				
Rhizosolenia sp. "A"	750—500																
	1,000—750																
	1,500—1,000																
	3,000—1,500																
Schröderella delicatula	750—500	r•															
	1,000—750																
	1,500—1,000																
	3,000—1,500																
Schröderella schröderi	750—500																
	1,000—750																
	1,500—1,000																
	3,000—1,500																
Skeletonema costatum	750—500																
	1,000—750																
	1,500—1,000																
	3,000—1,500																
Stephanopyxis palmeriana	750—500	r•	r•○														
	1,000—750																
	1,500—1,000																
	3,000—1,500																
Thalassionema nitzschioides	750—500																
	1,000—750								r○								
	1,500—1,000						r○										
	3,000—1,500																
Thalassiothrix species	750—500						+•○								r○		
	1,000—750														r○		
	1,500—1,000																
	3,000—1,500																

ID RELATIVE ABUNDANCE OF THE SPECIES (continued)

: 1961—1963 CRUISES

4	26	27	28	29	30	31	35	36	38	41	43	45	47	48	49	50	51	52	54	56	57	58	60	61	62	64	66	68
											r•																	
																				r•				r•				
																					r•							
	r•				r•	c•	r•		r•	r$^{\bullet}_{\circ}$	r•	r•								r•	r•	r•	f•	r•	r$_{\circ}$	r•		
	r$_{\circ}$	r•		r•	r$_{\circ}$	f$_{\circ}$	r•	r•			r$_{\circ}$	r•			r$_{\circ}$				r•				r•		r•		r•	
												r•												r•				
																					r•				r•	r•		
																			r•		r•							
																			r$_{\circ}$									
																			r•									
	r•			r•	r•															r•								
				r•		r•	r•																			r•		
	r•														r•											r•		
																						r•		r•				
																			r•									
																			r•									
																r$_{\circ}$												
																				f•	r•							
																					r•							
																					r$_{\circ}$							
																			r$_{\circ}$									
													r$_{\circ}$						r$_{\circ}$									
		r•		r•	r$^{\circ}_{\circ}$	+•			r$_{\circ}$	f•	r•												r•		c•	c•		
		r•			r$^{\bullet}_{\circ}$	+•	r$_{\circ}$		r$_{\circ}$										r•				c•	r$^{\bullet}_{\circ}$	c•	c•		
		r•											r•				r•		r•			r•	r•	r$^{\bullet}_{\circ}$	c•	c•		
																							r•		c•	c•		

TABLE III: SPECIES LIST, DISTRIBUTIO

STATION NUMBE

SPECIES	Depth Metres	4	5	6	7	9	10	11	12	13	14	15	16	19	21	22	2
DINOPHYCEAE																	
Amphisolenia species	750—500																
	1,000—750																
	1,500—1,000				r												
	3,000—1,500																
Ceratium candelabrum	750—500																
	1,000—750																
	1,500—1,000																
	3,000—1,500																
Ceratium extensum	750—500			r						r			r	r	r		
	1,000—750			r					r			r		r			
	1,500—1,000				r		r					r					
	3,000—1,500									r							
Ceratium fusus	750—500																
	1,000—750														r		
	1,500—1,000																
	3,000—1,500										r						
Ceratium geniculatum	750—500																
	1,000—750																
	1,500—1,000							r									
	3,000—1,500																
Ceratium pentagonum	750—500													r			
	1,000—750								r								
	1,500—1,000																
	3,000—1,500																
Ceratium tripos	750—500	r	r		r	r	r		r			r		r	r		r
	1,000—750			r	r		r	r			r	r		r	r	r	r
	1,500—1,000			r	r				r	r	r	r	r				
	3,000—1,500									r	r		r				
Ceratium vultur	750—500																
	1,000—750																
	1,500—1,000							r									
	3,000—1,500																
Dinophysis tripos	750—500							r									
	1,000—750							r									
	1,500—1,000																
	3,000—1,500																
Noctiluca species	750—500																
	1,000—750																
	1,500—1,000																
	3,000—1,500																
Ornithocercus species	750—500											r					
	1,000—750																
	1,500—1,000								r								
	3,000—1,500																
Peridinium species	750—500																
	1,000—750										r						
	1,500—1,000																
	3,000—1,500																

D RELATIVE ABUNDANCE OF THE SPECIES (continued)

: 1961—1963 CRUISES

4	26	27	28	29	30	31	35	36	38	41	43	45	47	48	49	50	51	52	54	56	57	58	60	61	62	64	66	68
																				f								
																					r							
				r	r		c													r			+	r		r		
					r		c																+		r	r		
							c																+	r	r			
																					r		+		r	r		
							c														r		+				r	
							c									r							+				r	
							c						r										+		r			
																							+		r	r		
																												r
																												r
		r	r		r	r	r												r	r	r		r	r	r			
		r	r	r			r												r		r		r	r	r			
		r			r		r									r		r	r		r	r	r	r	r			
																					r		r	r	r	r		
																				+								

TABLE III: SPECIES LIST, DISTRIBUTI

SPECIES	Depth Metres	STATION NUMB 4	5	6	7	9	10	11	12	13	14	15	16	19	21	22
Pyrocystis noctiluca	750—500															
	1,000—750															
	1,500—1,000															
	3,000—1,500															
Pyrocystis species	750—500				r	r						r	r	r		
	1,000—750				r				r				r			
	1,500—1,000			r	r						f	r			r	
	3,000—1,500												r			
OTHER MICROPLANKTON																
Trichodesmium species (Myxophyceae)	750—500	r			r		r									
	1,000—750			c												r
	1,500—1,000			r	r		r									
	3,000—1,500															
Halosphaera viridis (Xanthophyceae)	750—500	r	r		r					r				r		
	1,000—750			r	r						r	r	r			r
	1,500—1,000			r	r		r			r			r			
	3,000—1,500												r			
Codonella species (Tintinnoinea)	750—500															
	1,000—750															
	1,500—1,000															
	3,000—1,500															
Other Tintinnids	750—500						r				r					r
	1,000—750								r				r	r	r	r
	1,500—1,000						r		r							
	3,000—1,500									r						
Globigerina species (Foraminifera)	750—500															
	1,000—750															
	1,500—1,000															
	3,000—1,500															
Pulvinulina species (Foraminifera)	750—500															
	1,000—750															
	1,500—1,000															
	3,000—1,500															
Other Foraminifera	750—500															
	1,000—750															
	1,500—1,000															
	3,000—1,500															
Challengeria species (Radiolaria)	750—500							r								
	1,000—750															
	1,500—1,000															
	3,000—1,500															
Sticholonche zanclea (Radiolaria)	750—500					r			r							
	1,000—750							r	r							
	1,500—1,000								r							
	3,000—1,500															
Other Radiolarians	750—500	r	r		r	r	r	r	r		r	r	r	r	r	r
	1,000—750								r	r	r	r	r	r		
	1,500—1,000			r	r			r	r	r		r	r			
	3,000—1,500									r	r					

D RELATIVE ABUNDANCE OF THE SPECIES (continued)

1961—1963 CRUISES

26	27	28	29	30	31	35	36	38	41	43	45	47	48	49	50	51	52	54	56	57	58	60	61	62	64	66	68
																		r									
																		r									
				r	r																						
			r																								
			r	r											c												
																								r			
r	r			r	r	r	r											r									
r	r			r								r		r													
			r	r							r			r			r										
																						r					
		r																					r				
r																											
								r															r	r	f	r	
							r		f			r			r					r				r	r	r	
																				r	r	r					
																				r		r					
																										r	
																						r					
																							r				
																											r
								r		r																	
																							r				
																							r				r
																				r							r
																				r					r		
																								r	r		
	r			r	r		r					r	r	r	r		r		r	r	r		r			r	r
				r		r	r	r				r	r	r	r		r			r		r	r		r		r
								r		c	r	r		r	r			r			r		r		r		r
																				r		r	r		r		

A NEW APPROACH TO RESEARCH ON TUNA DISTRIBUTION IN SOUTH AFRICAN WATERS

J. G. Welsh

It is only during the past decade that an interest has been aroused in the possibility of establishing a South African tuna industry and in conducting research on the distribution and general biology of the tunas.

Since about 1960 both the Division of Sea Fisheries and the South African Museum have carried out programmes of exploratory fishing with standard Japanese long-lines in the area between Cape Hangklip and Saldanha Bay.

The results of these surveys* together with statistics from commercial catches have established the approximate geographical distribution of tuna in the area under consideration as well as the relative abundance of the four main species at different times of the year (Fig. 12).

The commercial catches extending over a period of some six years fluctuated considerably and at the moment are very low as a result of the small fishing effort. This is partly due to an apparent decline in the availability of tuna but more so to the poor market for the bluefin and bigeye species. The lack of a suitable market at the present is, however, no justification for the abandonment of research since unexpected factors could easily create a new demand for tuna both locally and abroad.

The research being carried out by the Division, at present only on a pilot scale, is aimed at gaining further knowledge of the effect of the hydrological environment on the distribution of the four tuna species. The only data of this nature available to date are surface temperature ranges—tabulated below—and details of the overall hydrology of the area obtained monthly though not usually at the same time as that at which experimental fishing took place.

The above table, together with other knowledge gained from experience, could be of considerable help as a guide to the most likely fishing areas but, as will be discussed below, a knowledge of the swimming depth of the tuna and the temperature of the water at that depth is likely to be more valuable.

It has been established by numerous research workers both in South Africa and overseas, that sudden changes in temperature act as a barrier to tuna which are indeed often massed near such temperature discontinuities. The latter are frequently also regions of high productivity. These discontinuities can, of course, be both horizontal—i.e. variation in surface water temperature—and vertical. In the latter case this is known as a thermocline such as shown in Fig. 13. This graph was obtained with the use of a bathythermograph which automatically plots temperature against depth on a smoked glass slide as it is lowered to the desired depth. The example shown was taken about 50 miles west of Cape Point in February 1965 and falls within the area where fishing has taken place. The top of the thermocline in this case lies at about 50 metres depth and is an example of conditions typical of the summer months when a thin layer of warm water of Agulhas Current origin flows over the colder Atlantic water, often reaching as far north as the latitude of Saldanha Bay. The surface temperature of 20·8°C on this occasion lies in the optimum range for yellowfin (see Table I) but in all probability it would be useless to set hooks at depths greater than 50 metres. As will be shown below, however, a fair proportion of the hooks of a standard Japanese long-line would in fact lie below these depths under normal conditions.

Fig. 14 shows the arrangement of a typical long-line. It is seen that the main line hangs in a loop (assumed to take the form of a catenary) and that the depths reached by the hooks will depend on the extent to which the floats drift together under the influence of wind, waves and currents.

In the case of the gear shown in Fig. 14 with suspension line and branch line each 15 metres and a main line 300 metres long, it can be shown that

TABLE I: SURFACE TEMPERATURE RANGES FOR THE FOUR TUNA SPECIES*

Species	Minimum Surface Temperature	Maximum Surface Temperature	Most favourable Surface Temperature
Bluefin ..	15° C	20° C	16—17° C
Longfin ..	15° C	23° C	17—18° C
Yellowfin ..	17° C	21° C	20—21° C
Bigeye ..	16° C	21° C	19—20° C

* DE JAGER, B. VAN D., C. S. DE V. NEPGEN and R. J. VAN WYK 1963. *Investl Rep. Div. Sea Fish.* 47: 1–40.
TALBOT, F. H. and M. J. PENRITH 1962. Synopsis of Biological Data on Species of the Genus *Thunnus* (*sensu lato*) (South Africa). Paper presented to the World Scientific Meeting on the Biology of Tunas and Related Species. La Jolla, Calif., 2nd–14th July, 1962.

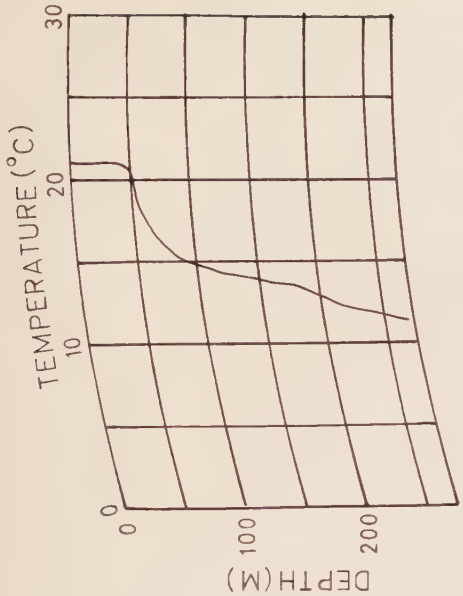

FIG. 13. Typical summer bathythermograph trace showing temperature in degrees Centigrade plotted against depth in metres

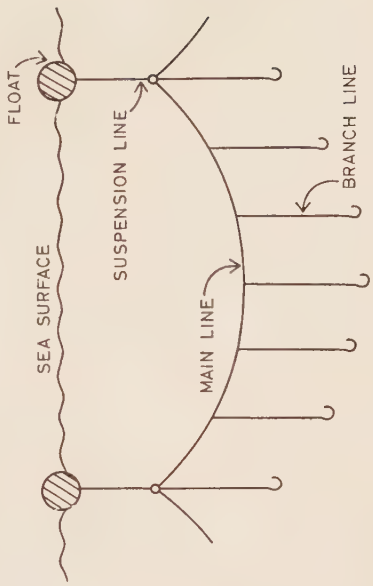

FIG. 14. Sketch of a typical commercial Japanese long-line

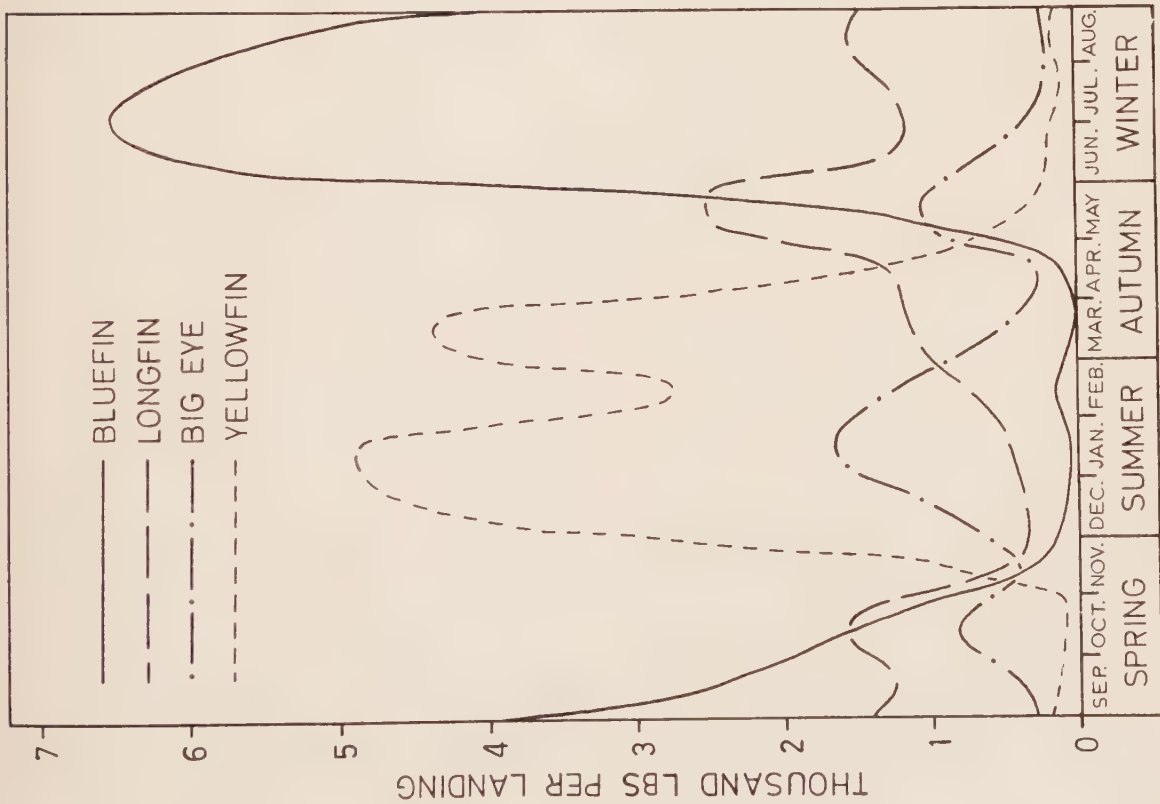

FIG. 12. Catch per landing made by a commercial firm during one year (1961–62)

if the buoys drift together by the quite normal amount of one-third—i.e. that they become 200 metres apart—the amount of sag is about 100 metres. This will result in a central hook depth of 130 metres. The hooks nearer the buoys will of course be affected to a lesser extent. Referring to Fig. 13 it is seen that under the prevailing hydrological conditions this gear cannot be expected to be very productive as most of the hooks would lie below the thermocline.

With the above difficulties in mind a modified long-line system has been prepared by the Division whereby hook depths are accurately known since each hook is supported by a float (Fig. 15). By arranging the branch lines in recurring series with increasing lengths, with the deepest hook extending to just below the thermocline, the swimming depth and temperature at that depth can be determined accurately for each fish caught.

The purpose of this experiment, therefore, is to acquire sufficient knowledge to be able to advise fishing craft as to the most suitable temperatures—both surface and subsurface—in which to fish at different times of the year and also the best depths at which to set their hooks for the four different species.

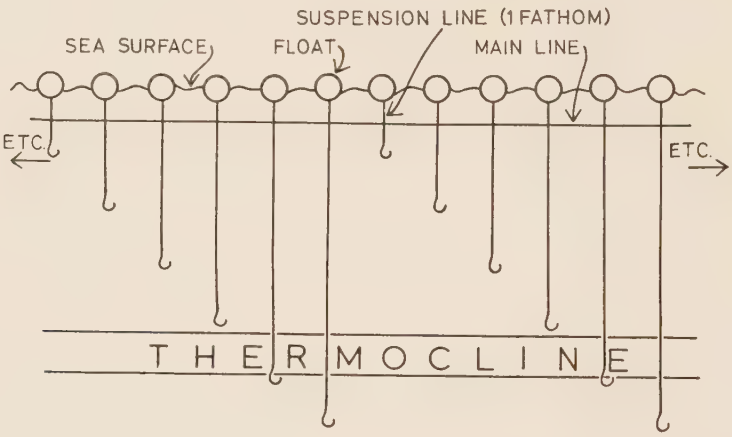

Fig. 15. Sketch of the new long-line gear showing how hook depth can be predetermined

THE CAPE SUBMARINE CANYON

PART I. BATHYMETRY

E. S. W. Simpson and Erica Forder*

Submarine canyons, trending roughly perpendicular to the continental margin, have been proved to be of relatively common occurrence on those continental shelves and slopes (particularly the latter) which have been surveyed in detail bathymetrically. Until recently, the only examples known to exist off the South African coast were the few canyons which cut deep channels in the narrow continental shelf and adjacent slope in the vicinity of St. Lucia Bay and Lake Sibayi. These can be traced for a short distance (±5 miles) off shore from the sounding data obtained during 1936–1937 by the Hydrographic Survey Office, and their seaward extension for some 15 miles is apparent from the sounding data obtained by R.V. *Atlantis II* on a track parallel with the coast in June 1965. During 1966–67 a very well-developed canyon was traced and accurately mapped to a depth of 1,500 fathoms on the steep continental slope east of Durban by the C.S.I.R. Oceanographic Research Group.

Three widely spaced sounding traverses made by the South African Naval Hydrographic Office suggested the existence of a canyon trending in a southerly direction from the St. Helena Bay area off the south-western Cape Coast. During the first deep-sea cruise (17–20 October 1966), undertaken by the new research vessel *Thomas B. Davie* of the University of Cape Town, the continuity of the canyon was established beyond doubt.

The Cape submarine canyon and its surroundings were mapped systematically during traverses (spaced 5–10 miles apart) through the area between the latitudes of Cape Deseada (32° 20′ S) and Cape Town (33° 50′ S) by using an Elac Eniff precision deep-sea echo sounder, as well as an Elsec proton precession magnetometer to gain additional structural data. The area surveyed is shown in Fig. 16, on which the black dots represent the ship's position at 15-minute intervals. Navigational accuracy is considered to be fairly good to the north of 33° 15′ S since calm weather conditions prevailed and the landward end of each traverse was fixed by reference to shore landmarks. Neither of these favourable circumstances prevailed during the latter part of the survey and positional accuracy in the southern half of the chart is not good.

The canyon was located 16 miles west of Cape Columbine where it forms a well-developed trench in the Continental Shelf, 100 metres deep and 2½ miles wide. Five miles to the north it no longer represents a significant topographic feature, and in St. Helena Bay it is either not developed at all, or covered by sand and silt spread out from the mouth of the Berg River.

South of the latitude of Cape Columbine the canyon becomes progressively broader and deeper, in some profiles showing two distinct channels separated by a ridge. Three typical echogram profiles are reproduced in Fig. 17, the location of each being shown in Fig. 16. The vertical lines on each echogram are spaced approximately 2·5 miles apart and the depth scale is given in each case so that the dimensions of the canyon profiles may be measured and compared.

Great variations in the morphology of the canyon and its surroundings are evident from the data obtained, particularly in the area of the southern traverses where the canyon reaches a depth of 1,500 metres and the local relief is of the order of 500–700 metres. These features will be described in detail at a later date when more intensive studies have been completed. Reconnaissance traverses have already shown that the canyon departs from its dominant north-south trend near latitude 34° S (approximately 60 miles west of Cape Town) swinging fairly sharply westward down the continental slope. At present there seems to be no ready explanation for its initial southerly trend which is oblique to the continental margin. Turbidity currents of mud and silt in suspension are almost certainly responsible for its excavation which is probably still actively in progress since none of the profiles indicate sediment accumulation on the floor of the canyon.

Each of the echogram records shown in Fig. 17 indicate dense fish shoals at depths varying between 200 and 300 metres. Profile Q shows two distinct shoals at different levels. On the chart (Fig. 16) the dark shaded areas indicate the traverse lengths over which such dense fish shoals were recorded and in each case the mean depth is noted. Apart from faint reflections from occasional scattering layers, no other such phenomena were recorded during the course of the four-day survey.

It is clear that the recorded fish shoals are closely associated with the axial zone and immediate flank areas of the canyon. This association is sufficiently consistent to suggest a causative relationship. The most obvious (but not necessarily correct) explanation is that the canyon provides a

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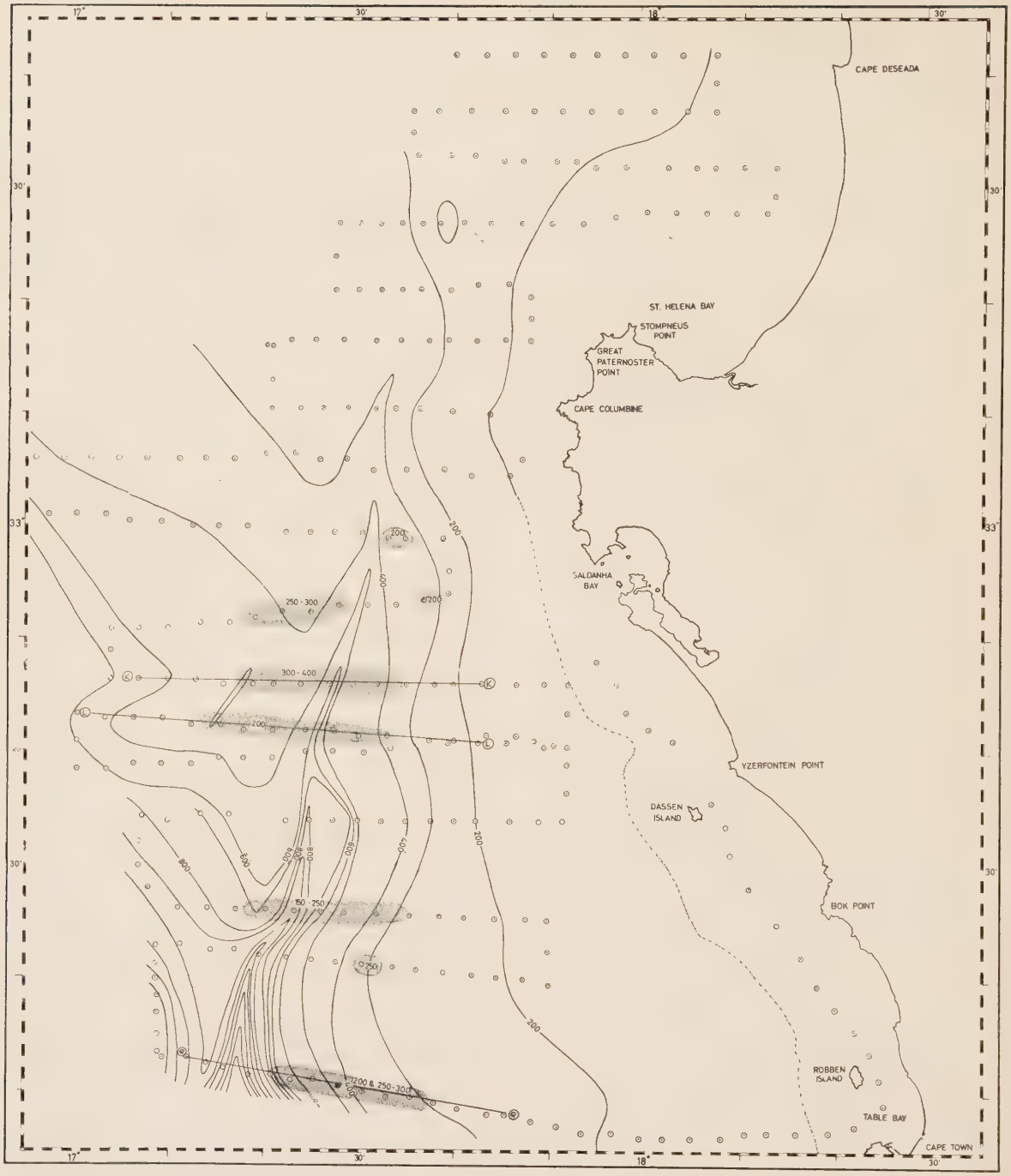

FIG. 16. Provisional chart showing the morphology of the sea floor bordering part of the Cape submarine canyon. Isobaths at 100-metre intervals. Black dots represent traverse positions at 15-minute intervals. Lines K—K, L—L and Q—Q refer to the profiles in Fig. 17. Shaded areas represent extent (and depth in metres) of fish shoals recorded on echograms

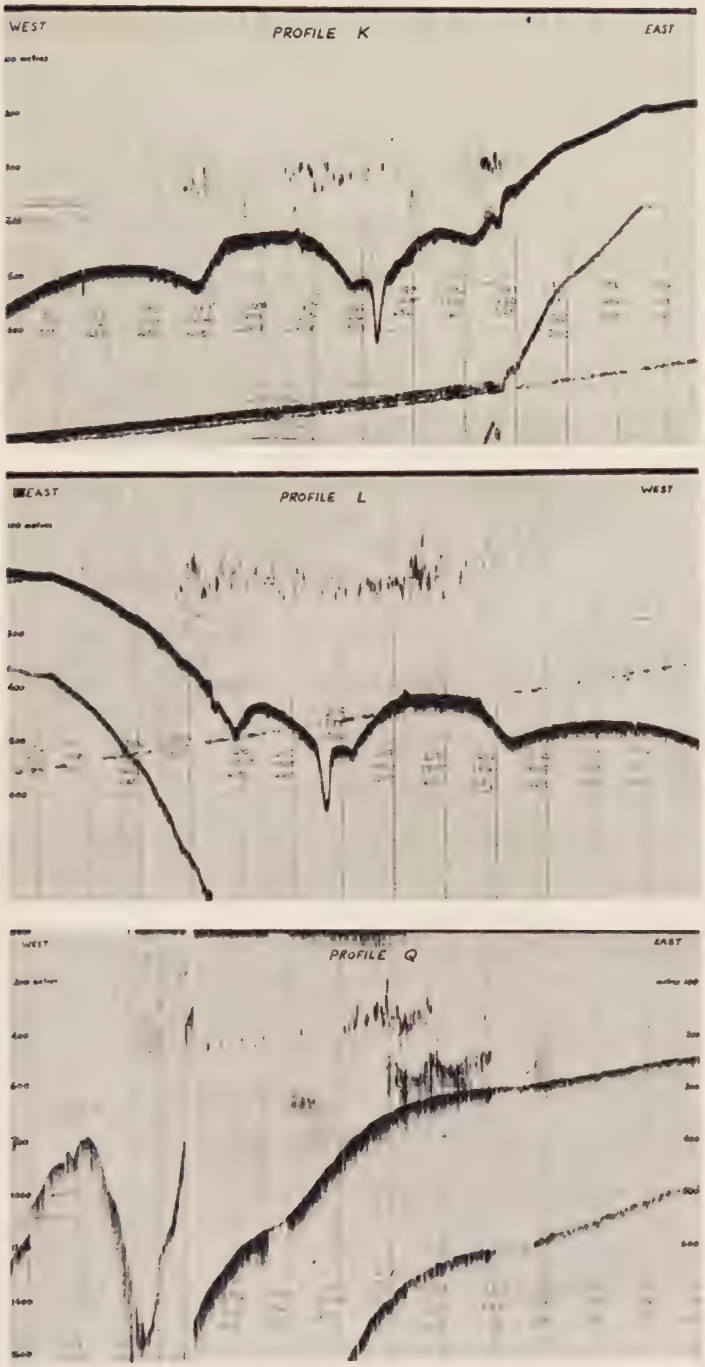

FIG. 17. Three echogram traverses (locations shown on Fig. 16) across the Cape submarine canyon, showing typical canyon profiles and evidence of closely associated fish shoals. Offset of sea-floor trace in Profile Q is due to scale change. Lower trace in each echogram is the first multiple reflection at twice true depth

channel for the localised rapid shoreward and northward movement of cold, nutrient-rich water upwelling along the continental slope. Under such conditions photosynthetic activity in the zone of sunlight penetration leading to localised high organic productivity would naturally provide a rich feeding and breeding area for fish shoals. Whatever may be the cause, it is suggested that the axial zone of the Cape submarine canyon may be considered to provide a useful guide to the fishing industry.

PART II. HYDROLOGY AND PLANKTON

A. De Decker

During a recent bathymetric survey of the shelf and slope off our West Coast by the Geology Department of the University of Cape Town, the echo-sounder revealed the widespread presence of fish shoals over or in the immediate vicinity of the Cape submarine canyon. This observation pointed to the probability of special environmental conditions being created by the presence of the canyon.

On 23 and 24 January 1967, advantage was taken of a short break in the monthly routine schedule of R.S. *Africana II* to undertake an exploratory trip to the Canyon, in order to gather some preliminary data on the prevailing hydrological and biological conditions.

Considering the prevailing northward movement of both the Central and the Antarctic Intermediate Water in the area (Shannon, 1966),* it seemed plausible to assume that the water arriving at the southern end of the Canyon will first be funnelled into it and then forced upward by the slope of the canyon bed. This mechanism would result in upwelling, with the concomitant phenomena of increased plankton biomass and fish concentrations.

The trip of *Africana II* was intended as a preliminary test of this hypothesis. With the limited time and the restricted personnel available, this could only be done in a most superficial way. The proposed programme for each station included water sampling with hydrological bottles for temperature, salinity and oxygen measurements. Vertical hauls with the closing zooplankton net, fishing between standard depths, were also considered necessary. A bathythermogram between 275 m and the surface would be taken at each station while the echo-sounder would be run continuously during the whole trip. It was planned to run two traverses at right angles to the axis of the canyon —one across its shallow northern part and the other one farther south. The distance between the two traverses and the number of stations on each was to be decided upon during the cruise, depending on the bathymetric situation encountered and the time available.

In practice, the northern traverse had to be limited to three stations, one over each bank on either side of the canyon and one over the canyon bed. When attempting to work three corresponding stations in a position about 25 miles to the south of the first three, it was found that the western bank of the canyon was reduced to a small hump in the general slope, too insignificant in size to warrant a station.

Weather conditions during the trip were unfavourable for navigation, as the sky was mostly overcast and a variable set was experienced. This explains the bad alignment of the stations (Fig. 18).

The echo-sounder did not record any traces of fish in the vicinity of the canyon during this trip.

The hydrological data obtained reveal a thermohaline structure which corroborates the hypothesis that northward-moving deep water is forced upwards within the canyon. At all depths below the thermo- and haloclines, the isotherms and

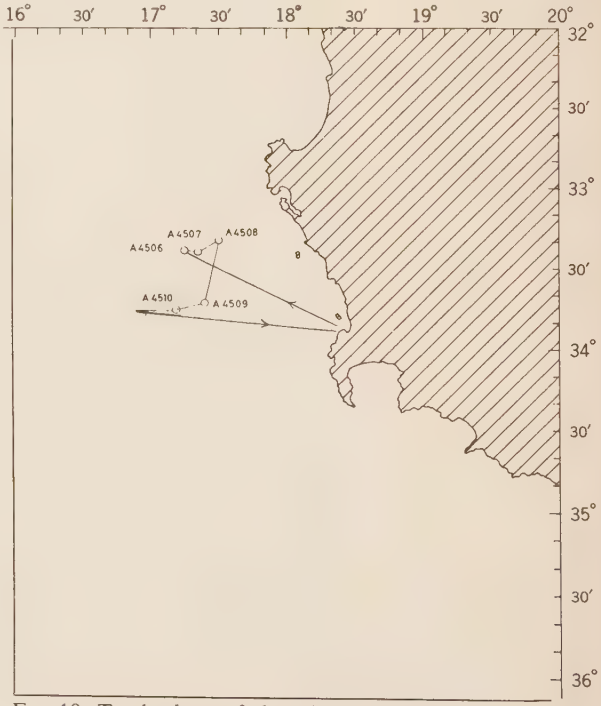

FIG. 18. Track chart of the trip of "Africana II" over the Cape submarine canyon

* SHANNON, L. V. 1966. *Investl Rep. Div. Sea Fish.* 58: 1–52.

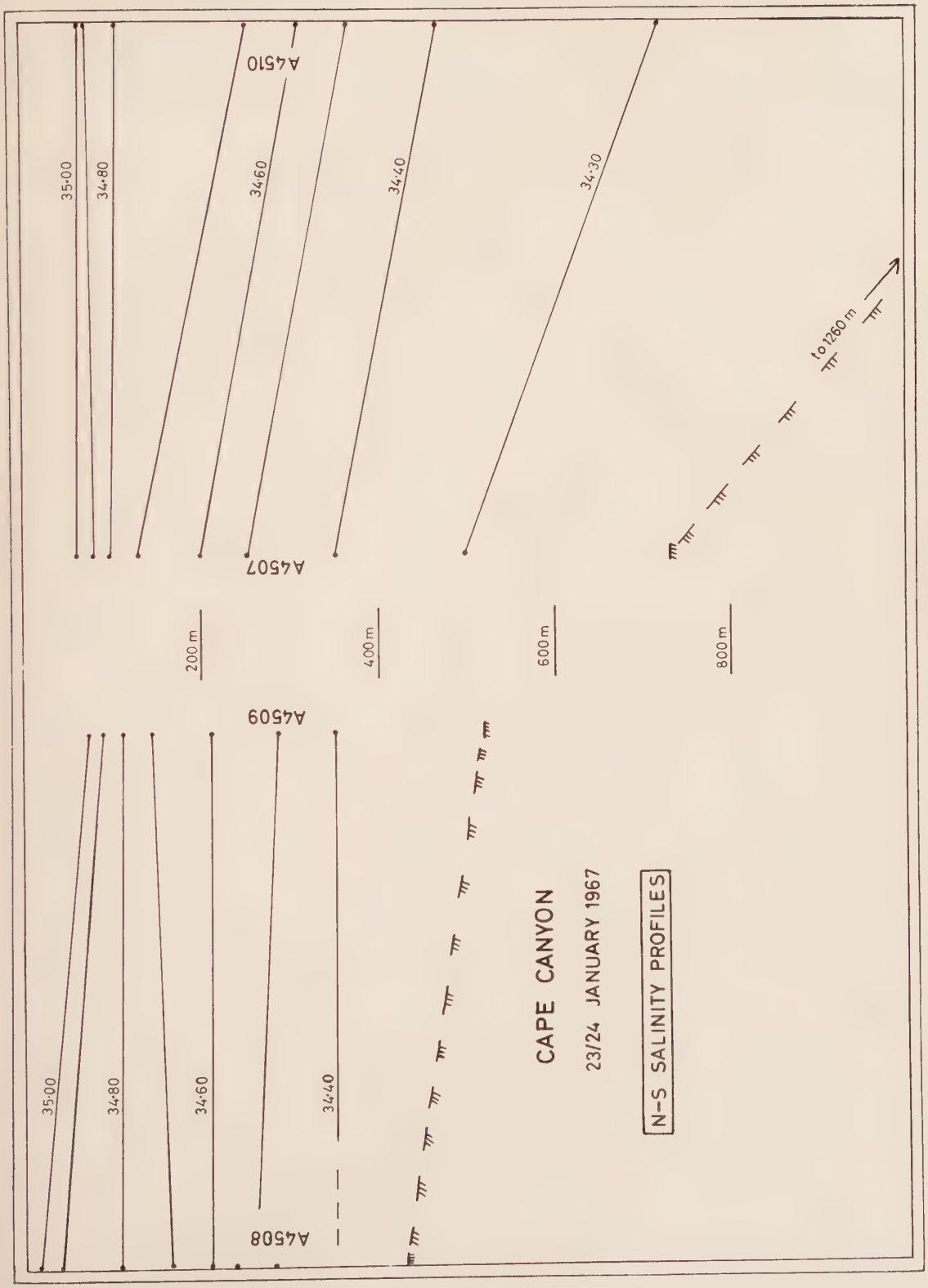

FIG. 19. Salinity profiles parallel to canyon axis

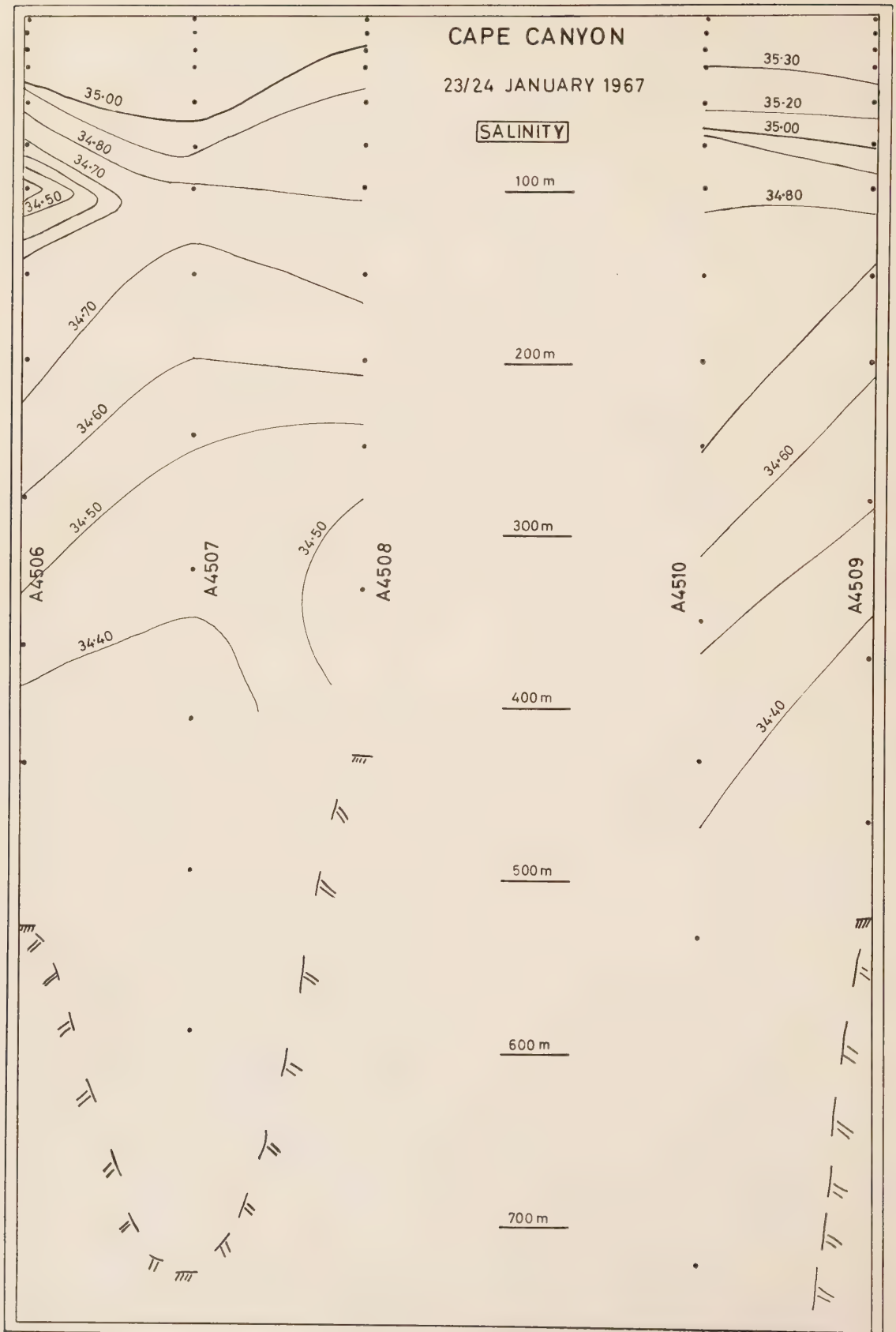

FIG. 20. Salinity profiles across the canyon

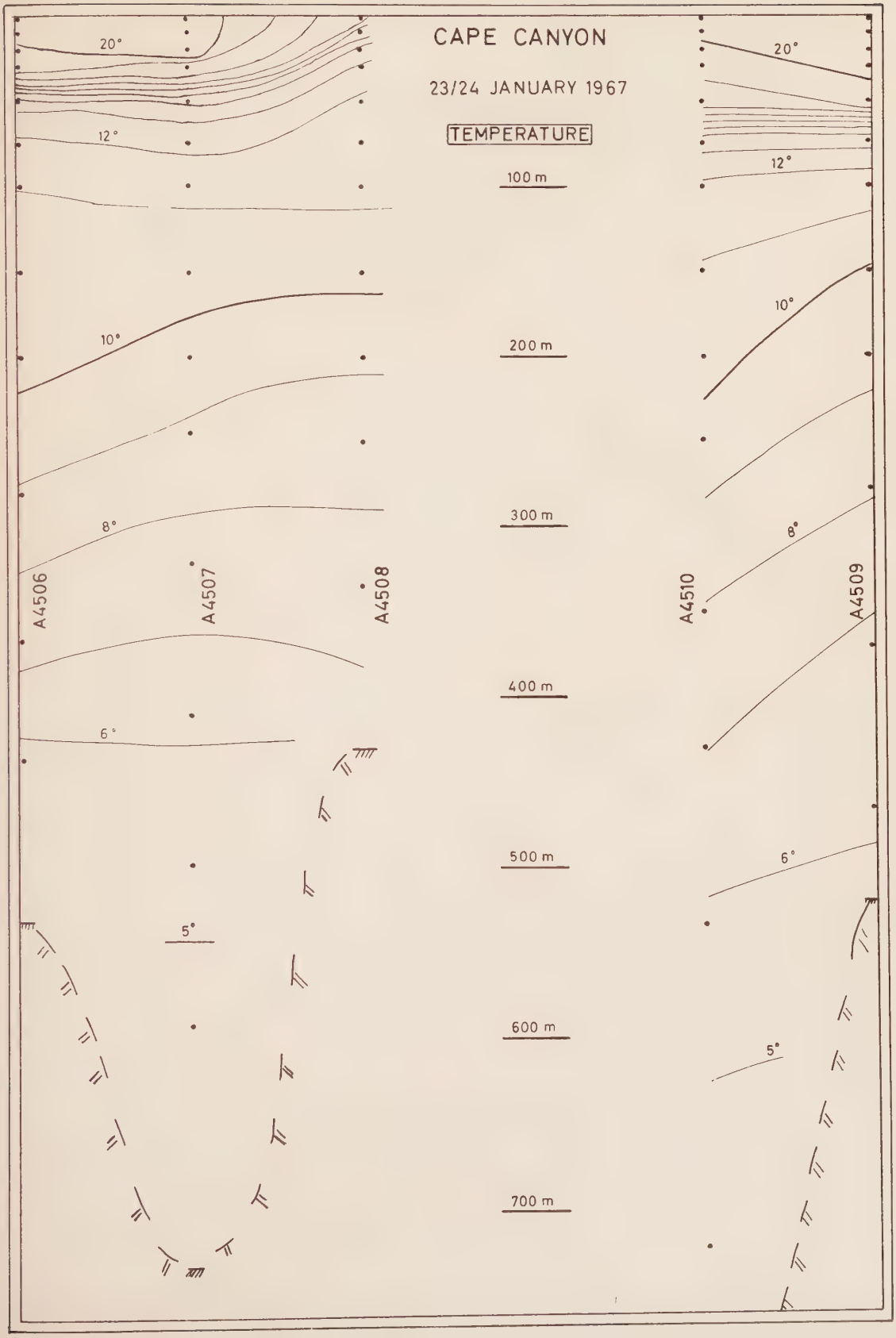

FIG. 21. Temperature profiles across the canyon

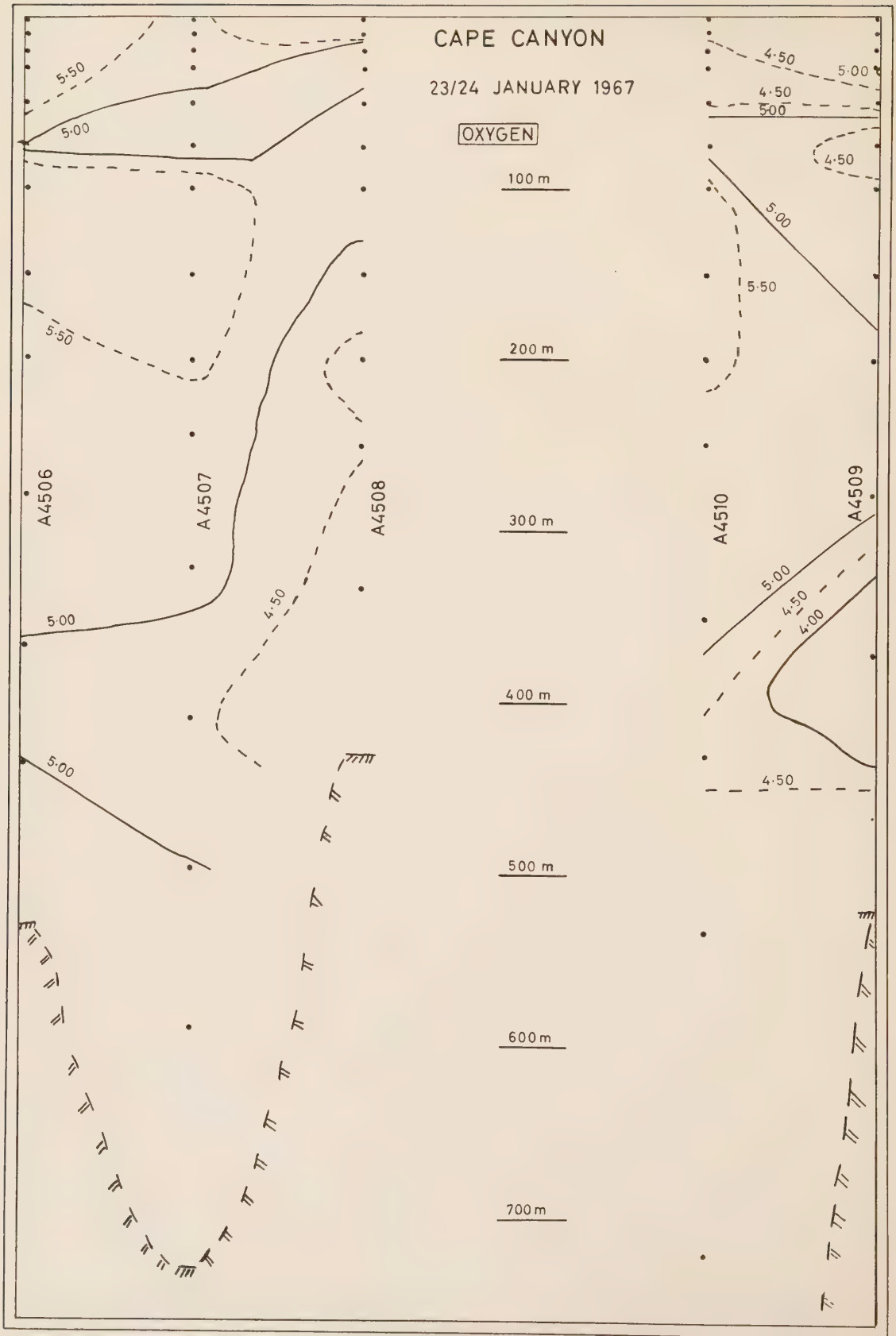

FIG. 22. Oxygen profiles across the canyon

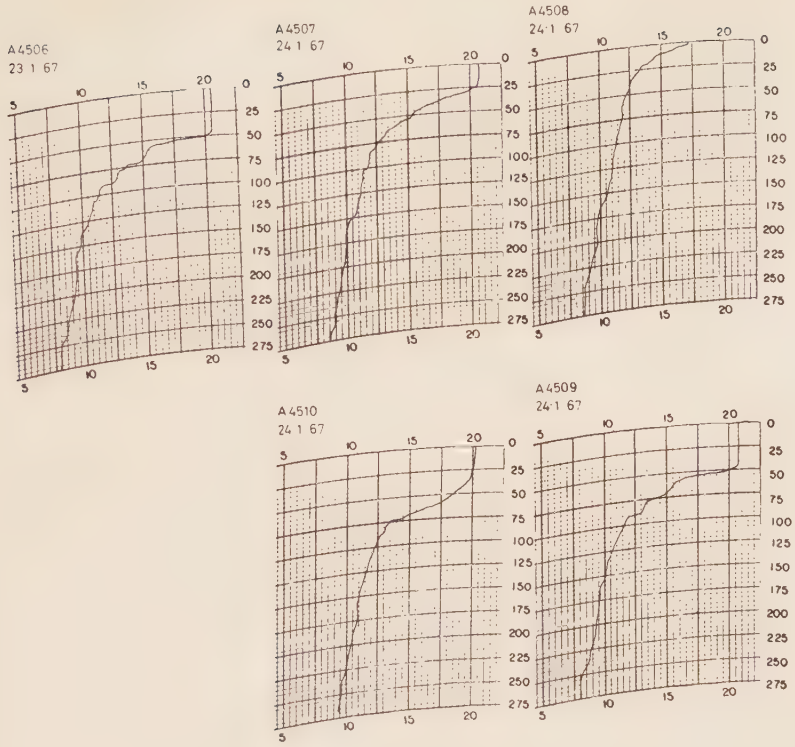

FIG. 23. Bathythermograms

isohalines between Stations A4507 and A4510 (axis of the canyon) are sloping upwards to the north, whereas over the eastern bank (Stations A4508 and A4509) the corresponding isolines between the northern and southern station depart very little from the horizontal (Fig. 19). The deepest isohaline recorded over the canyon bed (34·30‰) lies 220 m higher at the northern Station A4507 than at the southern Station A4510, whereas the canyon bed itself lies 545 m higher at the northern station than at the southern one. The isohalines in shallower depths are less steeply inclined, probably because they lie higher than the canyon banks so that the upwelled water layers can spread out laterally and become correspondingly thinner in the north than in the south. The thermocline at Stations A4506 and A4507, in the north, lies about 15 m closer to the surface than at the two southern stations.

In the uncompleted southern traverse, all isolines deeper than 100 m, i.e. temperatures below 12° C and salinities below 34·80‰ (Central Water!), show a steep upward slope against the eastern bank, whereas the surface layers do not show such a tendency. In the northern traverse, however, the thermocline is broken up on reaching the eastern bank and at Station A4508 upwelling conditions prevail in the surface water (Figs. 20 and 21). It would be interesting, on future cruises to the canyon, to determine how far a process of upwelling which starts near the northern tip of the canyon can extend towards the coast and northwards into St. Helena Bay in the absence of other sources of upwelling in the vicinity.

At the southern stations a fairly strong northward flow is evident from the thermohaline structure. On the northern traverse there is evidence of an eddy system over the axis of the canyon above 400 m.

The bathythermograms (Fig. 23) furnish us with certain details of the thermal structure which escape observation when hydrological bottles are used as a basis for analysis. The traces obtained at Stations A4506 and A4509 show a striking similarity, although these stations were situated on opposite banks of the canyon. These two traces may well be assumed to represent the structure of the upper 275 m in the area, when undisturbed by factors

such as upwelling. Apart from the strong main thermocline, two minor thermal discontinuities can be recognised at each of these stations: one between 72 and 75 m and one at 90 m. At the two stations overlying the axis of the canyon (A4507 and A4510), these characteristic thermal features are progressively obliterated apparently as a result of "undercutting" of the upper layers of warm water by turbulent mixing along the contact zone. This process is more advanced at the northern station than at the southern one, temperatures between 13° and 18°C being found 10 to 20 m deeper at the latter station than at the former. At the southern station, the thermal discontinuity at 90 m has disappeared but that around 70 m is still present; both have disappeared at the northern station. This supports the hypothesis of an upward encroachment of cold water progressing northward along the axis of the canyon.

The oxygen distribution offers a more complex picture than that of the temperature or salinity (Fig. 22). Nevertheless, an upward shift of both minima (values below 5·00 ml/l above 100 m and in 400 m) is clearly visible in the northern traverse as compared to their position in the south.

A series of vertical hauls with closing nets was made at each station to see whether the distribution of plankton could add any evidence to that derived from the hydrological data. The Indian Ocean Standard Net (113 cm mouth diameter, 330 μ mesh opening) was employed and the successive levels fished were standard depths (50–0, 100–50, 250–100, 500–250, 750–500, 1,000–750 m), modified only where it was attempted to get as close to the bottom as possible.

Little reliable evidence could be gathered from the plankton data. The significance of the settled volumes of the samples was often distorted by the presence in bulk of Salps and Doliolids. Another important source of error with vertical distribution of zooplankton is the daily vertical migration; many species living in deeper water during the day travel towards the surface during darkness. This phenomenon can involve a depth range of the same order as the thickness of the water layers sampled by successive closing net hauls. Unfortunately, the sampling times at the various stations were such that the northern traverse was worked mainly in the dark and the southern stations in daytime, consequently many species were likely to be found in shallower net hauls at the northern stations, quite independently of any upward shift of the water. Only when the difference between the levels at which a species is found in the northern as compared to the southern stations clearly exceeds the vertical distance which its own swimming power can reasonably account for, can the case be accepted as significant in the present discussion. In the plankton collections, only the Copepods were identified to species, mainly because they represented the most abundant and the most diversified group in the samples. Many of the 69 species found did occur at shallower levels in the north than in the south but since the amplitude of daily migration in a Copepod of average size can be of the order of 300 to 500 m, only four or five species could be retained as showing a significant difference in depth. This is a very poor indication indeed, especially when the small number of hauls (23) and the chance factor inherent in plankton sampling are also taken into account.

The numerical abundance and species diversity of the Copepod population offers a somewhat more significant picture illustrating the upwelling conditions (see "List of Species"). In the northern traverse, 17 species were much more abundant numerically than in the southern one, and 13 other species, known as inhabitants of intermediate depths, were found only there, and not in the south. Six species, four of which are typical deep-water forms, occurred exclusively at the two southern stations, along with five others (all typical warm-water inhabitants of the upper layers) which were markedly more abundant here than to the north. The increase in numbers of species as well as individuals towards the north gives a fair indication that a richer and more varied community finds its sustenance in the northern area, where the waters are enriched by upwelling.

In conclusion, it appears from the combined data that the situation encountered during our short visit warrants a more detailed investigation of the problems connected with the presence of the canyon. Among the aspects to be investigated, the following can be mentioned:

- the frequency, periodicity and intensity of the upwelling created by the canyon;
- the extent of the area covered by the dispersal of the upwelled water masses when they reach the upper layers and their impact on marine life (especially in and off St. Helena Bay);
- the relative importance of this source of upwelling within the general upwelling process off the West Coast;
- the connection with hydrological and climatological conditions in the far south.

The shape and orientation of the canyon makes it an adequate object in the study of internal waves. An internal wave travelling at a suitable angle

towards the canyon mouth is likely to be amplified on its way upwards along the gradually narrowing bed. This would facilitate the observation of the waves and of their effects on the mixing of the adjoining water masses and intermingling of their respective planktonic communities.

A reconsideration of the data collected during the numerous past surveys carried out by the Division of Sea Fisheries in the canyon area as well as in and around St. Helena Bay might well open up new perspectives for an interpretation of the periodical phenomena occurring in this important fishing ground and provide a key to their efficient monitoring.

LIST OF COPEPOD SPECIES

Only in N transect	In both transects		Only in S transect
Calocalanus pavo	S	*Acartia danae*	*Aegisthus mucronatus*
Candacia cheirura		*Acartia negligens*	*Arietellus giesbrechti*
Candacia varicans	N	*Aetidius armatus*	*Calocalanus styliremis*
Chiridius gracilis		*Calanoides carinatus*	*Conaea gracilis*
Chirundina streetsii	N	*Calanus finmarchicus*	*Metridia venusta*
Eucalanus longiceps		*Calanus simillimus*	*Spinocalanus* (2 *spp.*)
Euchaeta wolfendeni	N	*Calanus tenuicornis*	
Gaetanus minor	N	*Calocalanus plumulosus*	
Haloptilus longicornis	N	*Calocalanus tenuis*	
Haloptilus oxycephalus		*Candacia bipinnata*	
Haloptilus sp.	N	*Centropages brachiatus*	
Scottocalanus securifer		*Centropages chierchiae*	
Undeuchaeta plumosa	N	*Clausocalanus arcuicornis*	
	S	*Clausocalanus furcatus*	
	S	*Corycaeus spp.*	
	N	*Ctenocalanus vanus*	
	N	*Euaetidius giesbrechti*	
		Eucalanus attenuatus	
		Eucalanus elongatus	
	N	*Euchaeta acuta*	
		Euchirella rostrata	
	N	*Heterorhabdus spinifrons*	
		Lucicutia flavicornis	
		Mecynocera clausi	
	N	*Metridia lucens*	
	S	*Nannocalanus minor*	
	N	*Neocalanus gracilis*	
	N	*Oncaea conifera*	
	N	*Paracalanus parvus*	
	N	*Paracalanus aculeatus*	
	N	*Pleuromamma abdominalis*	
		Pleuromamma borealis	
		Pleuromamma gracilis	
		Pleuromamma piseki	
		Pleuromamma robusta	
		Pleuromamma xiphias	
		Pseudodiaptomus nudus	
		Rhincalanus nasutus	
		Sapphirina sp.	
	N	*Scaphocalanus spp.*	
		Scolecithricella dentata	
		Scolecithricella ovata	
		Scolecithrix danae	
		Scolecithrix bradyi	
	S	*Temora discaudata*	
		Undinula darwinii	
		Undinula vulgaris	

N *denotes species that were more abundant in the northern traverse, and* S *those more abundant in the southern traverse.*